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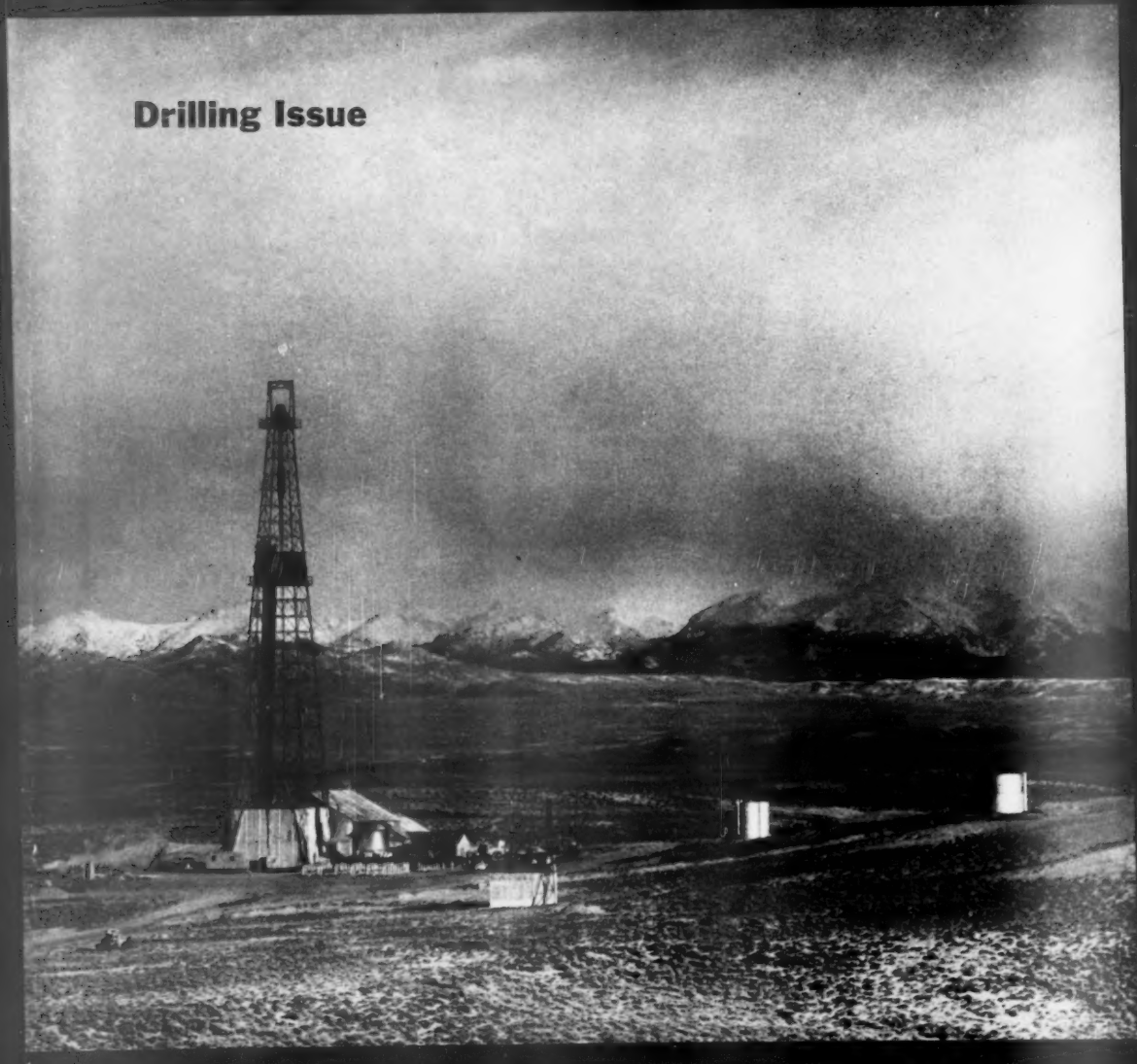
Petroleum Technology

Drilling Issue



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THE PROFESSIONAL MAGAZINE FOR PETROLEUM ENGINEERS

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Vol. III JUNE, 1951 No. 6

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On the Cover — No better illustration of the lengths (or in this case the depths) to which oil searchers will go for their product can be found than that portrayed on this issue's cover. This lonely scene near Rock Springs, Wyo., is marked dramatically by Superior Oil Co.'s Pacific Creek No. 1 well, an ill-fated venture abandoned at 20,521 ft. That man can drill a hole nearly four miles deep is a tremendous accomplishment. The achievement, however, would be further gratifying if oil were at the bottom of the hole.

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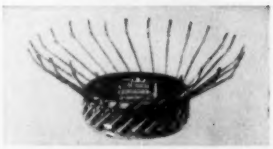

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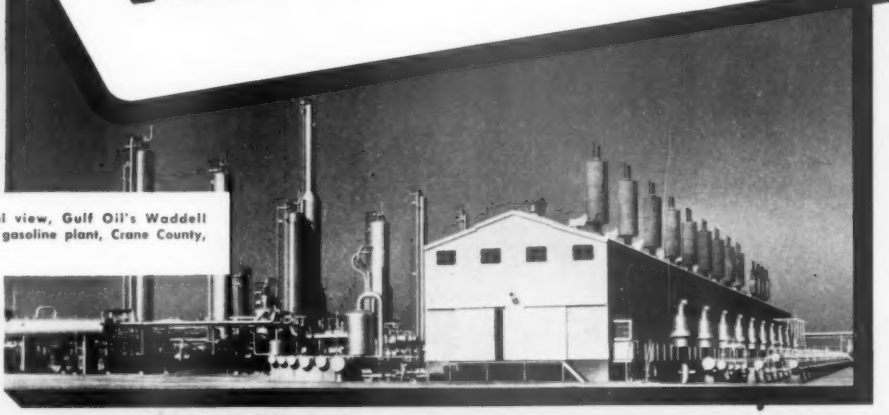
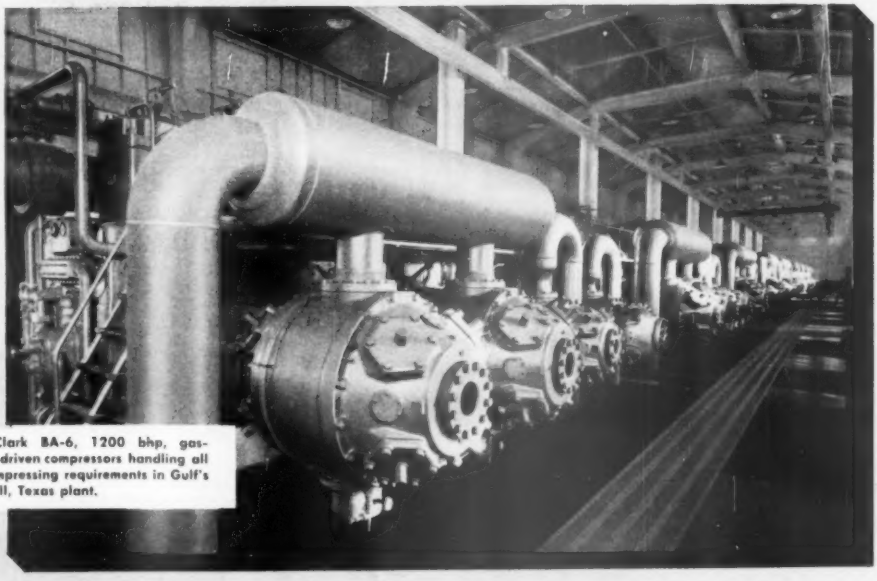


General view, Gulf Oil's Waddell natural gasoline plant, Crane County, Texas.



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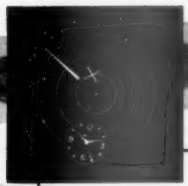

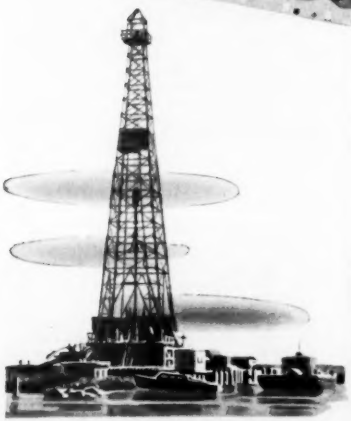

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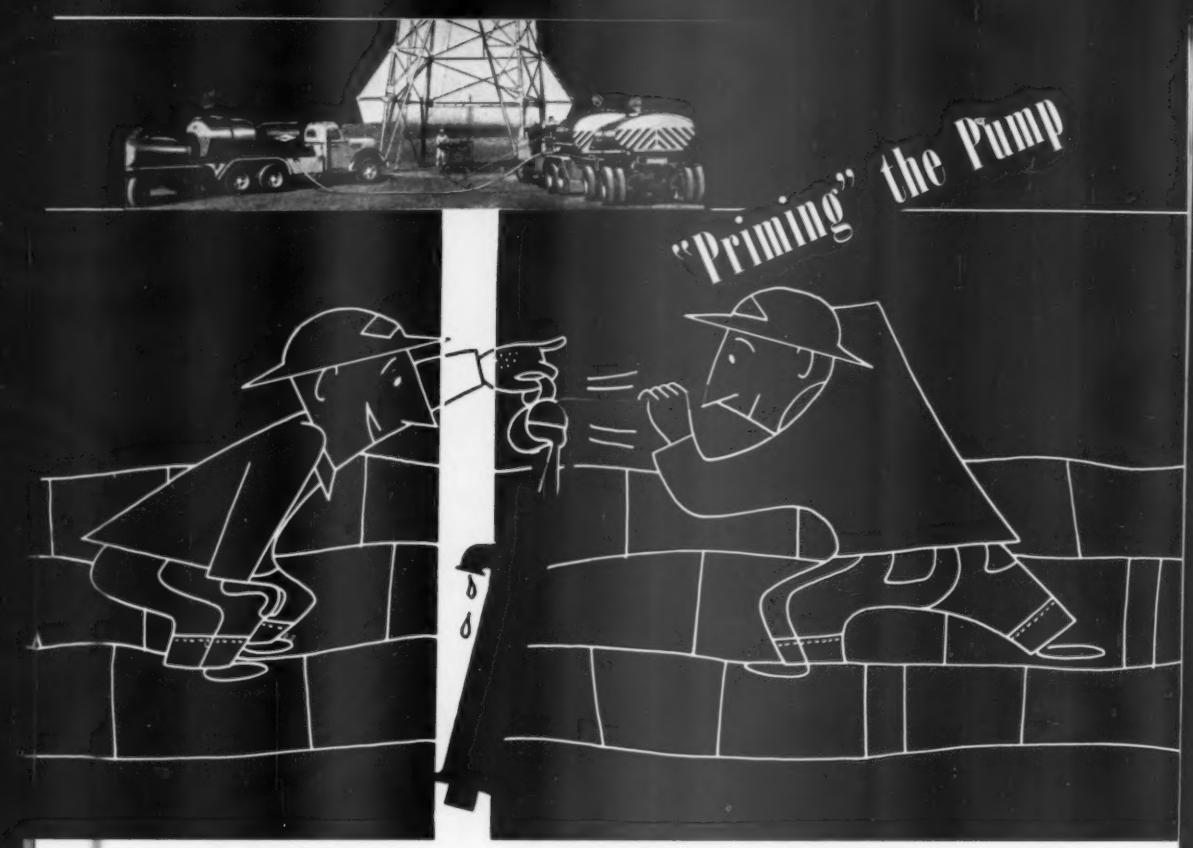

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Editorial Comment—

"*The Drill Is The Final Arbiter*"[1]

By Joe B. Alford
Secretary, Petroleum Branch
AIME

THIS IS a special issue of PETROLEUM TECHNOLOGY, published as such to focus attention on recent changes in our technical functions which will broaden and strengthen the Petroleum Branch. The expanding scope of our members' professional work has created the need for a division of our activities, and this has been satisfied by dividing our technology into the three basic fields of Drilling, Production and Natural Gas.

The Branch committee responsible for selecting technical papers for presentation and publication has been called the "Production Technology Committee" in recent years. Now it is simply the "Technology Committee," headed by a chairman, with divisions in each of the fields of Drilling, Production and Natural Gas, headed by vice chairmen. The hope is that this structure will result in a properly balanced division of our work into these primary fields. Committee officers for 1951 are: Earl M. Kipp, chairman; Jack Abernathy, vice-chairman for Drilling; Henry L. Waszkowski, vice-chairman for Production; and E. G. Trostel, vice-chairman for Natural Gas.

We chose to make this a "drilling" issue to emphasize the fact that many members of the Petroleum Branch are engaged in drilling and completion work as an inherent function of their profession. In a study conducted in the spring of last year, 23 per cent of our members indicated drilling as their *primary* technical interest and activity. Since only three per cent of the Branch members are classified as drilling executives or engineers, the logical conclusion is that *many members classified as Petroleum Engineers are engaged in drilling as their primary work.*

The same study indicated that 57 per cent of the Branch members are interested in Production as shown below:

	Per Cent
Production research	9.3
Reservoir engineering	18
Production, headquarters	17.2
Production, field	12.5
Total	57

THIS STUDY was not refined enough to give precise classifications of all phases of our work, but the breakdown above illustrates that 29 per cent of our members are engaged in production in the field and headquarters. Coupled with the 23 per cent engaged in drilling, this makes some 52 per cent of our members engaged in the operational phases of petroleum engineering.

The study also revealed that about two per cent of our members are engaged solely in natural gas engineering. This activity is actually inseparable from production research, reservoir engineering, etc., however, and the figure of two per cent is probably too low. It has been gaining in importance and recognition during post-war years as larger gas reserves and markets have been developed. The Natural Gas division of our Technology Committee was established to place appropriate emphasis on this growing phase of our work.

During recent years, membership demand for "practical" or "operational" papers has been widely voiced. The term "practical" as used here means papers or information that the member-engineer can apply in the daily execution of his work. Although it includes papers on research and reservoir subjects, it apparently means that more emphasis should be placed on the drilling, mechanical and production practice topics of current value. The most commonly advanced reason for this demand is that most engineers have little need to keep up their abstract mathematics, and have little occasion to apply personally what they learn from such papers. Apparently this arises from the fact that about half of our members are engaged in the operational phases of drilling and production.

A tabulation of all technical papers published in our *Transactions* from 1941 through 1950 is given below. This rough classification was done by paper titles only, and upon thorough examination quite a number of papers would be reclassified. Nevertheless, the tabulation serves to illustrate the broad outlines of our publications program during the past decade.

Subject	Number of Papers	Per Cent	
Drilling and Well Completioning:			
Equipment, methods, materials, practices	28	10.1	
Logging: Electric and Radioactivity	17	6.1	
Sub total			16.2
Phase relations and PVT data	28	10.1	
Reservoir engineering	56	20	
Reservoir performance and field studies	30	11	
Core analysis	14	5	
Sub total			46.1
Production engineering:			
Methods, equipment, practices	28	10.1	
Natural Gas Technology	23	8.2	
Offshore operations	8	2.9	
Miscellaneous	46	16.5	
Sub total			37.7
Total	278		100

ON THE basis of the present classification of the Branch membership, our publications program has been somewhat heavy on the side of research and reservoir-subject papers. This is not as inappropriate as it might first appear, because as a technical society we have an obligation to carry on progressive education, and this is done by reporting the results of research. However, the above analysis does serve to explain the membership demand for more "practical" papers.

This editorial is not intended as a criticism of our past or present publications program. It is presented to explain why our technical program is now undergoing a change. Unquestionably, there will be further changes as engineering meets the requirements for deeper drilling, and as the problems of production, reservoir and natural gas engineering develop.

An excellent analogy can be drawn from the statement by E. L. DeGolyer,[1] in speaking of oil prospecting, that, "*The drill is the final arbiter!*" (italics ours).

So it is with a professional society. The voice of the membership is the final arbiter of our work. This voice must be continually expressed and acted upon for progress in our technology.

[1] E. L. DeGolyer: "How Men Find Oil," *Fortune*, (August, 1949), 97.

Penetration Rates for Directional Drilling Operations

By Gordon Jackson
Eastman Oil Well Survey Co., Member AIME

INTRODUCTION

The purpose of this paper is to report the results of a study made primarily as a project to study the progress in directional drilling operations undertaken and completed during the past two and one-half years. During this period of time special records were kept so that the data when compiled could be presented in a short, significant, and useful manner. All the information was gathered on an area or field basis but will, for the purpose of this report and in respect to the limited space, be submitted compiled on a larger, more regional basis.

VOLUME OF DIRECTIONAL DRILLING WORK

A conservative appraisal of the total amount of supervised directionally drilled hole drilled by all directional drilling service companies in the United States during the year 1949 shows the figures to be in the neighborhood of 725,750 ft. During the first half of 1950, however, the directional drilling increased to a yearly rate in excess of 1,000,000 ft of deviated hole. The complete data on all of the directional wells drilled was not available as the directional drilling work was supervised by many different companies and many times carried on after the directional drilling supervisor was released. The curves and data which are illustrated in this paper represent the actual experience gained from averaging 405 directional wells totaling approximately 991,485 ft of directionally drilled hole on which definite records were kept during the period from January, 1948, to July, 1950. The records had to include complete time breakdowns to be valuable to this survey. The regional distribution of the wells included in this analysis are as follows: California, 267; Texas Gulf Coast, 54; Louisiana, 84; total, 405.

There was no attempt made to weigh or separate any of the original drilling reports and all true control or directional jobs in excess of 500 ft in length which were supervised by directional engineers were used in the study. The only variance from this policy is in the curves used for the Gulf Coast area where greater than normal improvement in directional drilling rates had been experienced in the last two years. The curves and records for this area are in the main divided into three groups because it has been felt that the caliber of the work now being accomplished in this area should be fairly shown and not tempered by work experienced even such a short time ago as two years. Therefore, the Gulf Coast records are dated with the calendar periods in which the wells used in the survey were drilled.

This paper was presented at the Fall Meeting of the Petroleum Branch, AIME in New Orleans, La., Oct. 4-6, 1950.

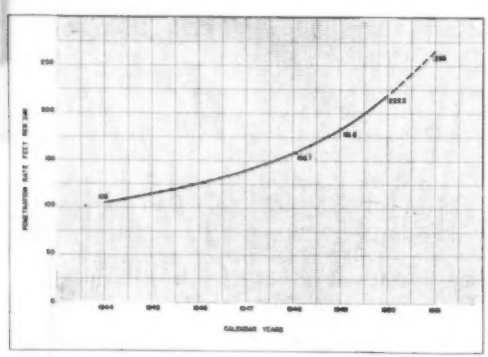


FIG. 1 — DIRECTIONALLY DRILLED AVERAGE PENETRATION RATE, FT PER DAY TO 10,000 FT, DOWNTIME EXCLUDED, SOUTHERN LOUISIANA AREA.

IMPROVEMENT IN DIRECTIONAL DRILLING PENETRATION RATES

Engineers in general now consider that a carefully controlled slanted hole, although somewhat more difficult to drill, is as mechanically perfect as a well drilled straight hole. Therefore, if the mechanical considerations of slanted and straight wells are comparable and all other factors considered equal, the best index of directional drilling performance is the penetration rates of the wells being drilled in the area under study. For many years it was the general opinion that directional drilling was hopelessly slow, but by applying straight hole methods to directional work and developing special tools and methods, the penetration rates have increased to where many applications for directional programs are economically feasible. This increase has not been made at the expense of quality as recently requirements for directional control are more rigid than ever before.

Fig. 1 illustrates this improvement in the overall penetration for the Southern Louisiana area. Other areas have shown a like improvement, but this part of the Gulf Coast area has shown the trend much more clearly and is therefore used as an example. The information in Fig. 1 has been based on all directionally drilled wells on which records were available during the years shown on the graph. To make the curve have true significance as far as the penetration rate was concerned, only the actual drilling time was compiled and averaged. Fishing, standby, and other lost down times were not counted in forming the averages shown in this graph so that variations in down time would not affect the actual penetration rate. On the whole the lost time will not amount to more than

Here is a progress report, covering some two and one-half years of activity in directional drilling of 405 wells in California, Louisiana, and the Texas Gulf Coast.

that experienced on straight hole drilling. The averages shown on this curve are ft per day to 10,000 ft depth for approximately 100 wells.

The improvement experienced in this area is shown to be 63.5 ft per day, or an overall improvement of 40 per cent since 1944. This steady progress will undoubtedly continue; and if this graph is extrapolated ahead one year, we could expect drilling rates to be in the neighborhood of 265 ft per day. The possible reasons for this marked trend are probably very numerous, but foremost among them are the better engineering methods which were used, such as mud control, specialized drilling tools, etc., and, most important, better planning prior to starting the actual directional work.

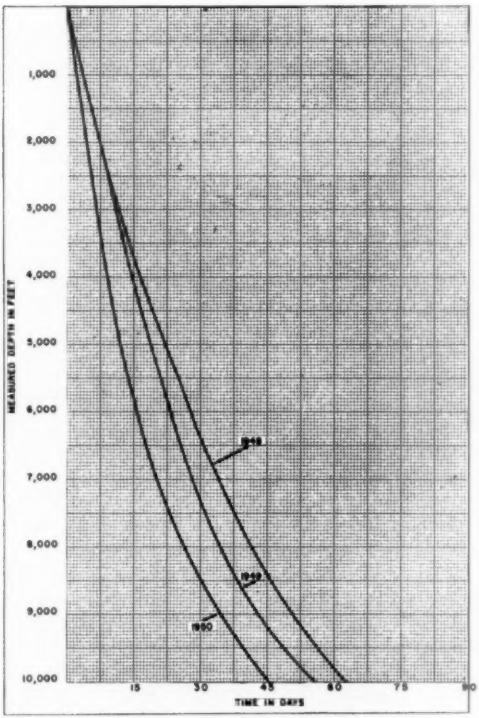


FIG. 2 — COMPOSITE DIRECTIONAL DRILLING PENETRATION IN FT PER DAY, DOWNTIME EXCLUDED, SOUTHERN LOUISIANA AREA.

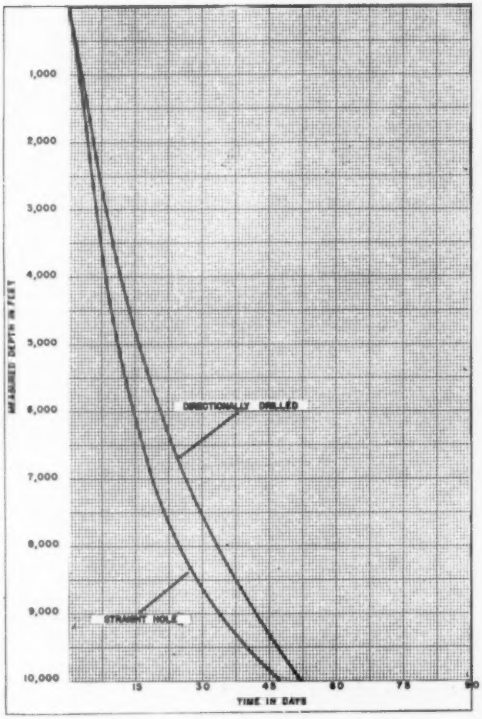


FIG. 3 — COMPOSITE DIRECTIONAL DRILLING PENETRATION IN FT PER DAY, 1950 AVERAGE, DOWNTIME EXCLUDED, SOUTHERN LOUISIANA AREA.

DISCUSSION OF DIRECTIONAL DRILLING PENETRATION RATE CURVES

The penetration rate curves for all areas used in this report are composite curves and were made in the following manner: Data sheets were set up so that all wells, drilling averages, and various time breakdowns could be tabulated. Averages for the drilling rate of each well for each 500 ft section drilled were calculated. Each of these individual wells averages were then re-averaged for each 500 ft section drilled and this figure in turn plotted according to depth to form the composite curves shown in this report. The data on these sheets include a complete study, such as down time, fishing time, logging time, etc., and thus any type of curve for any area could readily be drawn. The curves in this report are true averages, regardless of the number of wells, at any depth for all wells drilled through that section, and it is most remarkable that these composite curves are smooth and in the main do not demonstrate sharp breaks. In compiling the data it was observed that the average curve for all wells was much closer to the curve representing the fastest possible well than it was to the slowest possible rate. The probable reason for the actual average to be closer to the fastest rate is that most of the more recently directionally drilled wells encountered extremely few mechanical difficulties and progressed very rapidly.

It may well be that by compiling this type of data many of

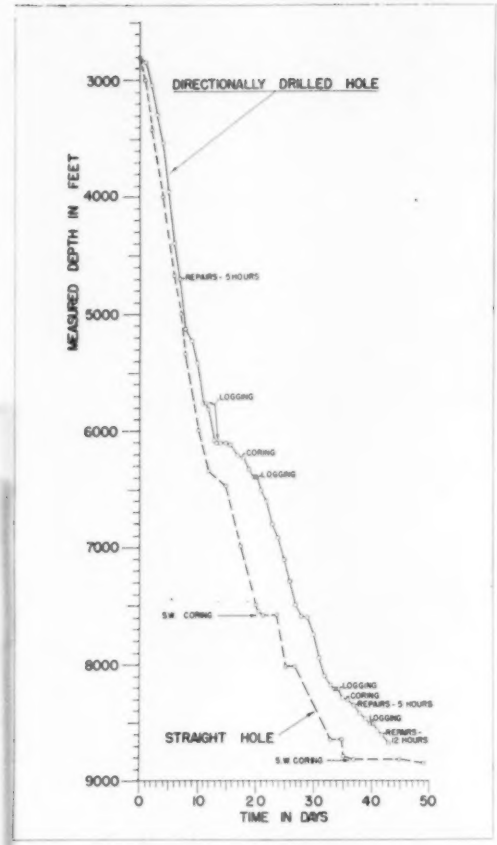


FIG. 4 — ACTUAL PENETRATION LOGS SHOWING COMPARISON OF DIRECTIONALLY DRILLED HOLE WITH STRAIGHT HOLE IN LOUISIANA GULF COAST.

our drilling problems can be divided regionally, rather than on a small area or field basis. If this is true, then this regional data would be very helpful in planning the directional drilling programs to fill in before an appreciable amount of drilling data would be available on a new field. As experience in a new area broadened, the program could be retailored to fit the new conditions. Also, data compiled on a regional basis is valuable in planning an isolated directional drilling job, which under present conditions, is generally undertaken on a purely experimental basis.

The average penetration rate for directional wells drilled in Southern Louisiana has, as shown in Fig. 1, increased each year since 1948. In order to more closely analyze the character of these increases the actual average drilling rate curves for each year are compiled and illustrated in Fig. 2. These clearly show that improvement in penetration rate has occurred at all depths and thus the improvement shown by the curves cannot reasonably be the result of the records from an isolated extremely fast drilling area. With the improvement so evenly spread to all depths one can assume that real concrete changes in the drilling methods and the planning of directional work have been made on basically all work done.

From 1948 to July, 1950, the curves for Southern Louisiana show a net reduction in overall time needed to drill directionally to 10,000 ft of 18 days which is an improvement of 28.6 per cent. Analyzing this another way, the industry in 1950 as a whole saved 216 drilling days in Southern Louisiana over what it would have taken in 1948 to drill the same amount of slant hole.

A comparison of straight hole penetration rates to directionally drilled rates is difficult to make unless it is made on a well-to-well basis or by using average curves which include many representative wells of both types. Comparisons have been made in which the slanted hole time closely approached or was lower than the straight hole rate. A typical example of a recently drilled directional well is shown in Fig. 4. This example demonstrates a straight hole which was drilled to 9,000 ft and an offsetting directionally drilled well on the same platform with a deflection of 1,200 ft, drilled to the same total depth in nearly the same time. However, it is felt the average well drilling rates will better illustrate the overall picture.

Fig. 3 is a comparison of the average curve to 10,000 ft for directional wells drilled in the South Louisiana area during 1950 with an average straight hole curve for the same general area. The data for the straight hole curve was furnished by

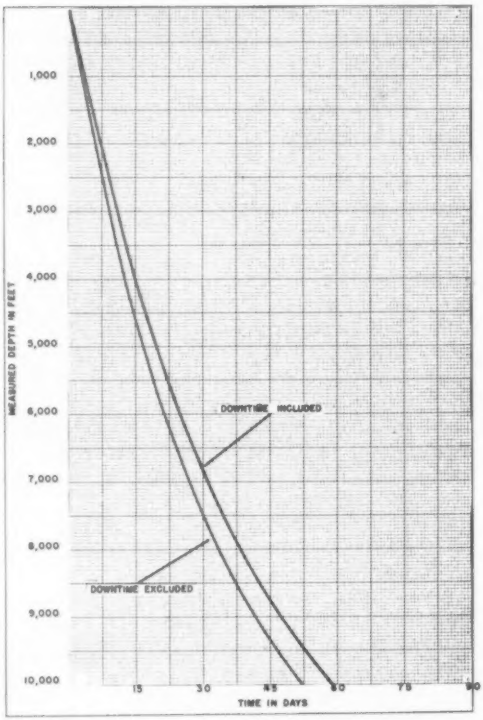


FIG. 5 — COMPOSITE DIRECTIONAL DRILLING PENETRATION IN FT PER DAY, SOUTHERN LOUISIANA AREA.

three major oil companies and was compiled in the same manner as the directional curves and on approximately the same number of wells. Total time for both types of wells were used and no attempt was made to differentiate between down time and drilling time. The straight holes which were averaged were extremely fast and this particular curve is probably a very fast average even for straight wells. In the analysis there were directional wells which closely compared with the straight well average but when all the averages were taken, straight drilling time was found to be 10.5 per cent faster at 10,000 ft depth.

The averaged penetration curves for all wells and all regions are shown in Figs. 5 to 7. These graphs are self-explanatory and each includes a second or faster curve which is representative of what the drilling rate would have been if all down time which occurred while directional supervision was in force, such as circulating, cementing, fishing, standby, etc., were eliminated. Naturally, it is impossible to eliminate all this time element; however, it could be investigated in detail as a possible avenue for improvement in overall directional drilling time throughout the industry. Much of this time is possibly a result of directional operations and could be reduced. The lost time percentage in the California fields is the smallest of any area and is probably explained by the fact that the directional drilling operations are concentrated which allows a good opportunity for advance planning. In

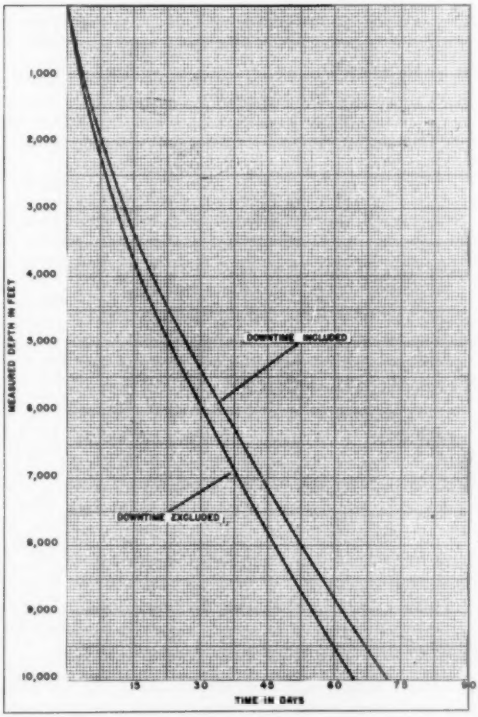


FIG. 6 — COMPOSITE DIRECTIONAL DRILLING PENETRATION IN FT PER DAY, TEXAS GULF COAST AREA.

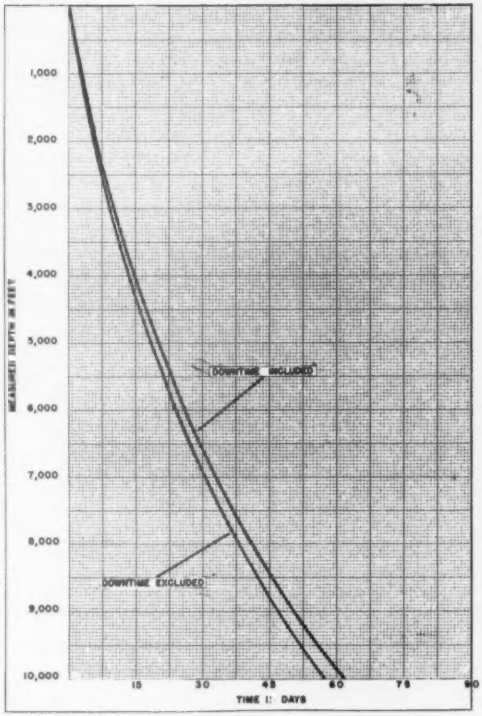


FIG. 7 — COMPOSITE DIRECTIONAL DRILLING PENETRATION IN FT PER DAY, LOS ANGELES AREA.

California during the first six months of 1950, the non-drilling time was 12 per cent of the total, while in the Gulf Coast this time amounted to 16 per cent.

THE ROLE OF DRILLING RATE CURVES IN PLANNING DIRECTIONAL PROGRAMS

In general, the main elements in planning a directional program are choosing the section for the slanted portion of the well, the proper tools and special equipment, and the degree of accuracy required by the geological structure. All other factors, such as drift angle, hole size, casing program, cylinder size, etc., more or less are governed by these first three elements.

Drilling time is ordinarily the greatest factor of cost and makes imperative a careful study of drilling records to pick the proper place to start and stop deflection work. The overall economic cost, including additional casing, may be less if the proper hole interval is used in obtaining the necessary deviation. If the required penetration information is at hand a reasonable decision can be made using drilling rate information in somewhat the following manner: If the straight hole data is high at the total well depth and the directional average is only comparable in penetration rate near the upper portion,

(Continued on Page 3, Section 2)

Advancement in Design and Technique of Rotary Fishing Tools

By F. L. Scott, Jr.
Brown Oil Tools, Inc.

The Industry has come a long way since the days when "bulldogs" were used in fishing operations. Here, a man well versed in the history of fishing reviews and marks the advancements made in tool design.

The art of recovering material lost or stuck in well bores is probably as old as the oil well drilling industry. The scope of this paper will be confined to improvements made in the basic types of fishing tools and the radical innovations that have taken place since the use of releasing spears and rotary overshots made the "bulldog" and wire line types of equipment obsolete.

To properly evaluate the equipment and techniques used, the classifications of work will be divided according to the operations involved. The first classification has to do with fishing work required while the well is being drilled. The second classification, which may actually comprise a modification of the first, involves the use of preventive equipment to reduce fishing operations while the wells are being drilled. The third classification involves the operations and tools employed in retrieving production equipment after the well has been completed.

DRILL PIPE RECOVERY

In the middle '30's an approved technique for removing stuck drill pipe from the hole employed a small fishing string and tools capable of going inside the drill pipe to cut the pipe and retrieve as much as was free. This was followed with "washing-over" operations, followed by external cutting to remove the portion freed by the rotary shoe and washover string.

Locating the Sticking Point

For the initial cut various rules of thumb and highly specialized guess work based on long years of experience enabled most fishing tool operators to make a fairly reliable determination of the stuck point in the drill pipe string. At best, the procedure was risky and in most cases maximum recovery depended more on the man and his techniques than it did upon the tool.

In the early '40's a system of nomographs was devised to graphically determine the sticking point from load and stretch measurements made on the rig floor. Several basic hypotheses used in these calculations necessarily limited the accuracy of any such system and an acknowledged error increased as the depth of the hole increased. This system gave at least a simple method of sticking point determination that did not involve long years of practice for its successful use.

Outside Cutting Tools

About the same time a screw feed outside cutting tool was developed to a point that gave an operating efficiency of 90 to 95 per cent. The technique involved with this type of tool was fairly simple and the tool itself and not the operator was more responsible for a successful job than heretofore.

Probably the highest development of technique was made by those men who operated weight-fed outside cutters during this era. These tools were operated by lowering the cutter over the free pipe as far as was practicable and then lifting the fishing string to engage an overshot section of the tool with the collars or tool joints on the pipe. The cutters were fed mechanically by the applied weight into cutting engagement with the pipe.

A refinement of this type of tool used a spring drive below the overshot section that cushioned the upward pull and allowed some flexibility of operation. A further development in the weight-fed tool provided a spring-driven retarding mechanism for the knives to further cushion their cutting action and relieve them from shock.

As can be well imagined, outside cuts below 10,000 ft with these tools required a great deal of delicacy and a high degree of care on the part of the operator. The principal advantage enjoyed by the weight-fed cutter lies in the fact that it can be built in a much thinner wall section than its more efficient screw-driven competitor.

The screw-feed cutter owes its efficiency to the fact that application of load and cutting action are entirely divorced. Thus a relatively large upward pull could be taken to straighten the pipe in the hole before the cutting operation was begun without feeding the knives into the fish.

Very keen competition was responsible for developing this equipment to the point where it was accepted on a near industry-wide basis as the most efficient means of recovering stuck drill pipe. These tools are in wide use all over the world and are probably still the best means for recovering stuck pipe in extremely difficult cases.

Improvements in inside cutters during this time were not marked. The design changed but slightly. The screw-feed principle was never successfully applied to an inside tool and weight-driven cutters with cushioned spring drives are still used with only slight modifications of structure.

Recent Advances

In 1946 a device was introduced using the electronic strain gauge principle for locating the sticking point in drill pipe and casing strings. This was a material advancement in the field and gave operators an assurance they had never before enjoyed in actually locating the stuck section of the pipe.

During the next year the successful application of an explosive jar blow to tool joint connections accompanied by left-hand torque began really to improve pipe recovery. Unlike the washover and cut technique, the back-off shot made it possible to retrieve all of the pipe from the hole without damaging any lengths by cutting or blowing them in two.

The back-off shot and the electronic strain gauge worked so well as complementary tools that several companies have arranged, through license agreements, to make the tools available to the industry as a unit. At the present time several companies offer the combined services. The technique of loosening threaded connections is, of course, an old one, but the

equipment for doing it successfully and repeatedly together with the advancement in techniques and equipment have made for the highest degree of efficiency in drill pipe recovery yet to be devised.

PREVENTIVE EQUIPMENT

Tool developments to provide preventive measures during this time were rapid. Most of this equipment was a wide departure from the conventional drill pipe safety joint. The advancement of drift indicators and single shot instruments for determining hole deviation played their part in keeping holes straighter to eliminate stuck pipe in "dog legs" and key seats and should be given full credit. Major improvements in drilling mud and drilling practices cannot be minimized under the heading of preventive tools and techniques. However, the jar safety joint, drilling spline and key seat wiper have done their part in the mechanical prevention of drill pipe fishing jobs.

Jar Safety Joint

Of these tools, the jar safety joint probably is the greatest single contribution, for it provides a means of instantly beginning fishing operations with the drill pipe in the hole.

Whether the pipe is stuck on bottom, or is stuck while going in or coming out of the hole, this tool provides the driller with a rotary jar for exerting tremendous hammer blows up or down at the instant the pipe is stuck. It also provides him with a means of swiveling his unstuck pipe while the drill collars are non-rotatably frozen in the hole. It further provides him with a bumper sub for springing the pipe up and down to produce hammer blows in either or both directions. As a last resort it provides him with a floating safety joint that does not require the delicate weight adjustment of the conventional tool to disengage the free portion of the drill pipe above the drill collars. Another modification of this tool is found in the drilling splinejoint in combination with a safety joint which provides neither swivel nor jar but does provide a bumper sub action in combination with a safety joint.

The drill collar stabilizer or key seat wiper assists in many cases in removing key seats, ledges or other internal obstructions to the safe removal of drill pipe and thereby has made its contribution as a tool and as a drilling technique.

Another tool that has contributed greatly to prevent expensive fishing jobs while drilling is a modification of the old grip-ring which enables the operator to use his drill pipe as a kelly joint in carrying on immediate remedial operations at the time his pipe gets stuck.

The tool consists of a spline joint which operates through a mating splined bushing set in the drive bushing socket of the rotary table. At the top of the splined joint there is a bowl and slip mechanism bult for engagement with the drill pipe. The slips are fed into position by a rapid-lead screw thread so that a tight gripping contact can be maintained even under the most severe applications of torque. The use of this tool in conjunction with the jar safety joint or the spline safety joint in most instances will prevent a major fishing job. The use of these tools in combination has saved the drilling industry an incalculable expense.

The shaped charge, in as far as fishing operations is concerned, is still in its development stage and probably will take the place of open-hole shooting operations where dynamite was formerly employed to sever the pipe to allow its removal from the hole. Inside jet cutters using shaped charges are still being pioneered, and it appears that their successful use will some day be a reality.

RETRIEVING PRODUCTION EQUIPMENT

In removing production packers, well strainers and sanded-up tubing strings from producing wells the rotary jar, inside cutter, and releasing spear enjoyed the greatest use up until a few years ago. The advent of the hydraulic pulling tool and its techniques almost completely removed the old practice of "cut-and-jar" from this phase of the fishing tool scene. This tool, in its various modifications, supplies the most economical means yet devised for removal of tools from a cased hole. The inside cutter and releasing spear are still involved.

Hydraulic Pulling Tool

These pulling tools enable the operator to exert many times the pulling capacity of his rig on the fish and enable him to remove stuck objects with a minimum amount of time and expense.

In many cases entire liner strings, several hundred feet long, can be easily withdrawn with only one application of the pulling unit.

Structurally the tools consist of an anchor section for engaging the casing and a telescoping pressure cylinder which is made to be connected to a fishing tool. In operation the fishing tool is engaged with the fish, the telescoping pressure cylinder is extended, the anchoring section is set to engage the casing, and pressure is applied to the telescoping cylinder. Application of pump pressure causes the cylinder to telescope and thus applies a tremendous pulling load to the fish. This pulling load, of course, is resisted by the casing.

There are three modifications of the hydraulic pulling tool on the market at present, with good evidence that there will probably be more. These range in pulling ability from ratios of 50:1 up to 90:1 and above. The figures are not true ratios but are simply factors by which the pump pressure can be multiplied to give the dead load pull in pounds. Some of these tools are designed so that additional pressure cylinders can be added to increase the pulling capacity.

It appears at present that the simplest structure involving the least amount of special technique employs an anchor section separate from the pulling unit so that it can be as close or as far away from the pressure cylinder as desired. This equipment uses direct application of pump pressure to set the anchoring device rather than the conventional cone and slip construction.

The cone-slip anchor tends to bind under the severe loads used and requires hydraulic assistance from the tool to effect its release. It can be seen that tools employing the cone and slip construction for an anchoring device can prove hazardous should a leak develop in the operating string after a load has been placed on the pulling unit. In this event pump pressures required to release the anchoring section could not be applied.

The particular tool under discussion employs the simplest possible arrangement of operating valve and does not involve the use of jay slots to set the tool ready for operation. Further, it releases the pulling pressure at the end of its stroke and simultaneously releases the anchoring section by the accompanying drop in pressure. In this manner the pulling of the fish from the bottom of the hole only requires alternating pick-up on the tubing and application of pump pressure.

The pulling tool has enabled operators to perform their fishing operations with the tubing string that is withdrawn from the well and eliminates the costly operation of coming out of the hole with the tubing in singles and going back in with a string of drill pipe.

There are still many requirements for improvements in existing tools and practices. There are many projects under way in the engineering departments of most of the fishing tool manufacturers, and it is felt that the next few years will see as many major improvements in equipment and techniques as have the last few, priorities and material shortages permitting. ★ ★ ★

The Responsibility of the Engineer

Reported by Harry D. Vaughan
Southwest Texas Section

The complexity of the oil industry today places a greater responsibility on the petroleum engineer than ever before. His responsibility has increased in direct ratio to the number and gravity of the problems which confront us as an industry, not only in the actual finding, producing, and refining of oil, but also in combating the forces which tend to undermine the oil industry as a free enterprise. It is the responsibility of the engineer today, because it is the responsibility of the engineering profession, to recognize these problems and know how he, as an individual, can help deal with them.

These were the remarks of Harold Decker, president of the Houston Oil Co. of Texas, at a meeting last month of the Southwest Texas Section in Corpus Christi. He was speaking of the responsibility of the engineer to the industry in its activities of drilling for and production and refining of petroleum.

The services of the petroleum engineer are in demand from the time he graduates, Decker said. Because of his specific, specialized training he can fill a definite and necessary place in any oil company organization. He can know his job thoroughly and completely — but he starts to assume the responsibility of his profession only when he becomes actively interested in knowing about the oil business as a whole, when he is not content to limit his interest and knowledge to the particular phase of the business which his job defines, but has a genuine desire to do his job and do it well and in addition learn something of the work which those about him are doing. It is a fine thing to be a specialist in your line, but, also, there is always a ceiling on how far a specialist, whose interest is in his job alone, can go up the ladder of success, for no matter how far he may progress in his particular field there is always a certain level of employment where other things besides the knowledge of one job are considered for a promotion.

HAROLD DECKER

The employee whom management picks for promotion is invariably the man who has been curious enough to want to know more than has been required of him — the man interested in all phases of the business, who likes people and is able to work with others and assume responsibility for them, the employee whose activities outside of his business world show some initiative and a desire to improve his lot in life — in short, the employee who is broad, who goes beyond being a specialist in one line of endeavor.

As the engineer's responsibility to his company increased during the last few years, so has his responsibility to his community and to his country grown. In this scientific age the engineer with his scientific education and training has a greater obligation to society than does his neighbor, whose training has not been along those specific lines; but he has not assumed the responsibility which his profession has placed upon him. Look around you and see who runs your company, your city and state, the Nation. Just almost anybody except the engineer. How many engineers have been President of the United States? To my knowledge only one — Herbert Hoover. But because of his training and clear thinking he will go down in history as one of our ablest presidents. Go on through Congress and you find very few engineers representing us politically. We have civic organizations that strive to build our cities. We have city and county governments that directly affect our daily lives. And our responsibility goes beyond just paying taxes and voting at election time. It means taking an active part in community affairs and politics.

Membership in the AIME and an active participation in its affairs will do much to help the engineer have the right perspective on what he is doing and on how it fits into the overall picture of his company's activities and objectives, and will help him assume the responsibility which his profession has placed upon him. ★ ★ ★

Wyoming Chapter Holds First Annual Meeting

The first annual meeting of the Wyoming Petroleum Chapter was held in Casper May 4. Three papers were presented during the course of the session. They were "Work of the Casper Office of the U. S. Geological Survey," by J. R. Schwabrow of the U. S. Geological Survey; "Reservoir Study, Torchlight Field, Wyoming," by Martin Hegglund of Stanolind Oil and Gas Co.; and "Drilling Mud Problems in the Rocky Mountain Region," by Gary Davis of the Davis Mud Sales Co.

The technical session was followed by a dinner meeting. Richard W. French, Petroleum Branch, AIME, chairman, spoke informally.

New officers for the current year were presented at the dinner meeting. They are Sidney B. Richards of Stanolind, chairman; Robert D. Stottlemyer of National Supply Co., first vice-chairman; F. Raymond Wheeler of Chemical and Geological Laboratories, second vice-chairman; and R. D. Ferguson of the U. S. Geological Survey, secretary-treasurer. ★ ★ ★

A Chemical Service for the Improvement of Oil Recovery

Reported by John Clayton Jacobs, Jr.

North Texas Section

One hundred and ten members and guests of the North Texas Section heard Paul D. Torrey describe last month a new recovery process involving the use of CO_2. Torrey's review of recovery problems and description of the CO_2 process follow.

During the past two decades great progress has been made in the development of techniques for improving the efficiency of oil recovery. It is, however, very significant that most of the important improvements have been of a mechanical nature, such as the adoption of uniform well-spacing patterns, the development of better methods for the completion of wells, the purification of the injection media, and control of the injection of fluids so as to apply the most effective pressures and volumes to the reservoir. Improvements in the control of production of fluids have been of equal importance.

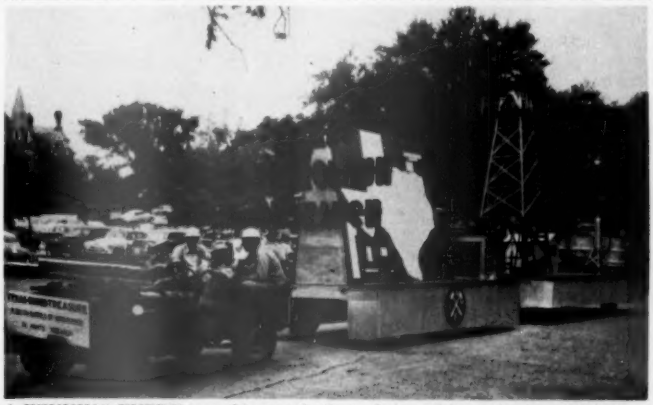
Most of these improvements have tended to accelerate the recovery of oil, or have provided other economies in operation. Therefore, it has been possible to recover oil from thin or deep reservoirs which, otherwise, might not be operated profitably. However, none of these improvements has resulted in a reduction of the residual oil saturations, which usually are in the range of from 20 to 30 per cent of the total pore volume of the reservoir, even under the most favorable primary or secondary recovery mechanism. One of the best informed authorities on oil reservoir behavior estimated recently that a reduction of 1 per cent in the present recovery limit would increase the recoverable oil reserve of the United States by around 1 billion bbl. Consequently, there has been a great incentive for further improvement in oil recovery techniques.

A consideration of the equation of radial flow of fluids through porous media will disclose immediately that the most promising opportunities for increasing oil production will be found in the control of relative permeability effects and in the reduction of the viscosity of the reservoir fluid. Some measure of control over permeability can be obtained by the shattering of the reservoir by explosives, by the rupture of the rock resulting from the penetration of a highly viscous liquid, or by the solution of carbonate rocks by acid treatment. The effects of these operations, generally, are confined rather closely to that part of the reservoir in the immediate periphery of the bore of the treated well. Similarly, it is physically possible, but probably in most cases uneconomic, to inject solvents into the reservoir or to heat the reservoir fluid in order to reduce viscosity. Therefore, it would seem obvious that some form of treatment that will affect the physical chemistry of the retention and displacement of oil from porous rocks, in connection with conventional fluid injection operations, should have the most attractive possibilities for the profitable recovery of increased quantities of oil. Any treatment that would accomplish this objective, of necessity, will have to penetrate the reservoir just as completely as would be the case if gas or water were used alone.

It will be evident that any form of chemical treatment will require effective isolation of the horizons to be treated, and, subsequently, to be produced. Valuable chemicals, and, in arid regions water itself cannot be wasted by injection into strata where no benefit can be anticipated. Recognizing the need for better equipment for the selective chemical treatment of reservoir rocks, the writer has devoted several years to the perfection of a hydraulic packer assembly that is now being used successfully in the acid treatment of the carbonate reservoirs of certain West Texas oil fields. This equipment may be employed with equal effectiveness for the control of other forms of chemical treatment.

It has been known for some time that certain chemicals, particularly those possessing the property of reducing the surface tension of water, even at very low concentrations, will increase the recovery of oil in water flooding experiments. These compounds are referred to frequently as being "surface active" as a result of their behavior at a liquid surface. When they are mixed with water, their molecules exhibit the unique tendency of collecting at the contact between the liquid and a solid or between the liquid and a gas. Thus, when the normal surface of water molecules is replaced by these totally different groups of atoms, the physical relation between the water and anything with which it is in contact is changed radically.

Artificial control of interfacial tension between water and oil by the use of surface tension depressants has so



A WINNING ENTRY was this parade float of the Student Chapter of AIME at the University of Texas. It took second prize in the "most educational" division of the annual Texas Round-Up parade of the university. The float consisted of two parts, one devoted to oil research and the other to production of petroleum.

far failed in practical application because of the tendency of the surface active compounds to be adsorbed on the surface of the reservoir. The advancing water front, therefore, is depleted of these reagents before any beneficial effects can be realized. The amount of chemical that will be required to provide for effective penetration of a reservoir and its cost has been, in consequence, entirely out of proportion to the value of the additional oil that might be obtained.

The writer, his partners, and associates are interested in exploiting the application of new chemical processes for increasing the recovery of oil, that do not, so it is believed, possess characteristics that will make necessary the use of excessive quantities of reagents. Specifically, we are interested principally in: (1) the application of the ORCO process, in which carbonic acid is injected into oil-bearing rocks in connection with water injection operations, and, (2) the use of certain remarkable surface active compounds, either by themselves or in conjunction with the use of carbonic acid.

The ORCO Process

Original discoveries on uses of carbon dioxide in solutions and mixtures as an aid to oil recovery have been made by James W. Martin, of New York, over a period of several years. Martin has discovered that under certain ideal conditions of pressure and temperature carbon dioxide will react with some of the constituent compounds of crude oil to produce unstable solvents or surface active compounds, thereby causing certain parts of the oil to act as a solvent or displacing agent unto itself. When the fluid is brought to the surface and the pressure is reduced in a separator, these compounds in large part will break down into crude oil and the combined gas, which may be reused after it is separated from gaseous hydrocarbons. Laboratory tests have been successful in reducing oil saturations in reasonably homogeneous sands down to the low level of from 8 to 5 per cent of the total pore volume. Also, it has been indicated that the permeability of the reservoir rock to oil is increased which can serve to increase the rate of oil recovery.

Some of the possibilities for the use of carbonic acid to improve the recovery of oil have been discussed recently by George Weber.[1] A current field test of the process in Alleghany County, New York, which has been in operation for about 18 months, has resulted in a production of oil 10 times greater than that obtained from adjacent flood units that have been affected only by conventional water injection. The high recovery efficiency indicated by over 1,000 laboratory flooding tests with carbonated water has been confirmed by engineering studies of analyses of cores obtained from the area affected by the injection of carbonic acid.

The results obtained to date from the use of carbonic acid encourage the belief that this process may be applied successfully to watered-out and marginal areas of the Penn Grade territory, and elsewhere. Currently, a carbonic acid injection project is being commenced under excellent control in a Bartlesville sand field in Northeastern Oklahoma, and studies are in progress in the Southwest to determine a promising field for an experimental injection of carbonic acid into a limestone or dolomite reservoir. Laboratory work indicates that the injection of carbon dioxide may be particularly effective in carbonate reservoir rocks.

There are many possible applications for the use of surface active compounds in the production of oil. The application of some of these compounds has been receiving a great deal of our attention, and certain possible uses to which they may be employed will be described.

Low concentrations of fatty amines, of cationic fatty amine acetates, and of water soluble cationic quaternary ammonium salts have proved to be extremely effective, in competitive tests with the products of other chemical manufacturers, carried on in the Bradford Field during the past year (1950), as bactericides and corrosion inhibitors. Combining an effective, low-cost bactericide with an effective, low-cost inhibitor will represent a great and economic advance in the conditioning of water to be used for surface cooling and for subsurface injection. It is notable that these chemicals do not react with the mineral salts that are present in most connate waters to form insoluble precipitates that would tend to plug the pores of the oil-producing formation.

J. N. McGIRL, above, was installed in May as chairman of the Mid-Continent Section. Other officers who will serve during the 1951 - 1952 term are Jack H. Beesley, vice-chairman (programs); G. C. MacDonald, vice-chairman (membership); John H. Jennings, secretary-treasurer; C. H. Danchertsen, M. B. Penn, and A. E. Smith, executive committee, Tulsa representatives; Harold S. Kelly and E. S. Messer, executive committee representatives from outside Tulsa

Primary Corrosion Control

Laboratory work has indicated superior control of corrosion resulting from hydrogen sulfide and salt water by the use of small quantities of oil-soluble dialkyl quaternary ammonium salts and water-soluble quaternary ammonium salts. An experimental field application of these compounds appears to be justified.

Laboratory tests have indicated the utility of using an acidic water solution for the prevention of flocculation and swelling of clay minerals when they come in contact with water. However, acidic waters cannot be used continuously without experiencing damage from corrosion. Use of an effective corrosion inhibitor in connection with the injection of a slightly acidic water will be commenced in the near future in an Oklahoma field where the results from water flooding have been inferior in past operations on account of hydration of clay cementing materials, which has served to reduce the permeability to water to such an extent that adequate quantities of water cannot be injected at safe pressures.

Increase in Water Injection Rates in Tight Formations

Tests recently conducted in the Bradford Field have shown that a treatment of the sand with a fairly concentrated solution of a non-ionic, *N*-substituted fatty acid amide will increase the relative permeability of the reservoir surface to water substantially. By such treatment water injection rates have been increased with no increase in the injection pressure. Wide application for this type of treatment is indicated in formations possessing low permeability. Conceivably, this form of treatment might eliminate the need for the detonation of explosives against reservoir rocks, thereby leaving the bore of the well in such condition that subsequent

Continued on Page 4, Section 2

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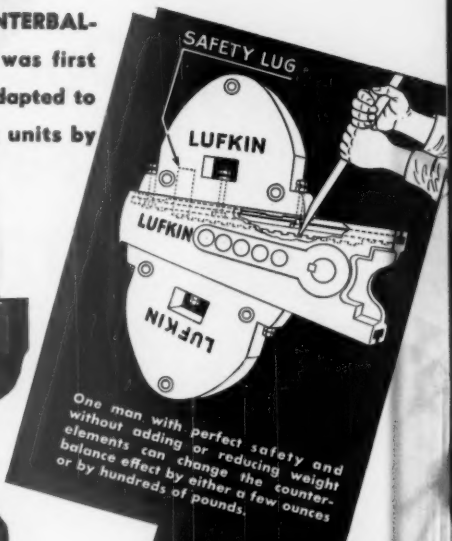

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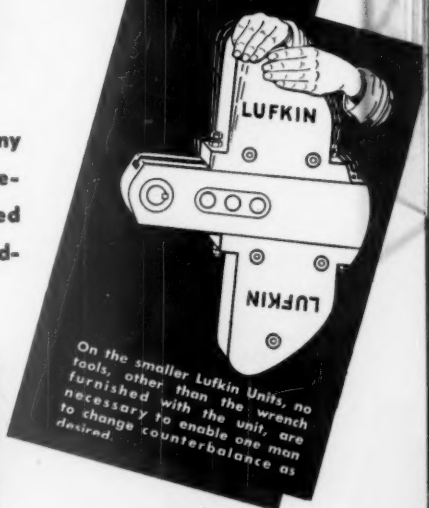

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PLASTIC FLOW PROPERTIES OF DRILLING FLUIDS—MEASUREMENT AND APPLICATION

J. C. MELROSE AND W. B. LILIENTHAL, MAGNOLIA PETROLEUM CO., DALLAS, TEX.

ABSTRACT

The application of Bingham's law to the behavior of drilling fluids in a rotational viscometer permits the expression of viscometric data in terms of plastic viscosity and yield value, the flow properties of a plastic fluid. A commercially available rotational viscometer is described, and when modified to a multispeed type viscometer, is shown to provide a simple and convenient instrument for the measurement of these properties both in the laboratory and in the field. The data obtained are shown to be useful in defining and understanding mud control problems relating to chemical treatment and to the hydrodynamic behavior of muds.

INTRODUCTION

The highly complex drilling fluids which are required for deep drilling often give rise to new and unusual mud control problems. Rapid and economic solutions to these problems may require, on the one hand, better understanding of the changes which contaminants and chemical treating agents produce in the colloidal and inert solids of the mud, or, on the other hand, closer control of the hydrodynamic behavior of the mud. The latter objective obviously can be achieved only if a correct rheological analysis of the flow behavior of drilling muds is available and if this is accompanied by the appropriate rheological measurements. The purpose of this paper is to describe such measurements in the field, and to show how the resulting data can be of value in solving difficult mud control problems.

It is now generally recognized that Bingham's law of plastic flow can be utilized in describing the hydrodynamic behavior of drilling fluids in the non-turbulent flow range. Beck, Nuss, and Dunn[1] have recently applied this law to the flow of mud in small pipes, and Rogers[2] has reviewed the rather extensive literature on this subject. So far, however, the use of Bingham's law has been restricted to the analysis of mud flow in pipes or capillary tubes, and it has not been directly applied to the flow in rotational viscometers. In the work to be reported, the Reiner-Riwlin[3] equation for the flow of a plastic fluid in a rotational viscometer has been utilized to permit the expression of multispeed viscometric data in terms of plastic viscosity and yield value, the two absolute flow properties of a plastic fluid.

With regard to the application of the e measurements, the calculation of the relationship between pumping rate and pressure drop, both in the drill pipe and annular space, has long been a subject of interest. Beck, Nuss, and Dunn,[1] following Caldwell and Babbitt,[4] base their calculations for non-turbulent flow on Buckingham's integration of Bingham's law for pipe flow and measurements of the plastic viscosity (rigidity in their terminology) and yield value. In the case of turbulent flow, Fanning's equation is employed, and the pressure drop is relatively insensitive to the flow properties of the mud. Since flow in the drill pipe is likely to be turbulent at usual circulation rates, the plastic flow properties will chiefly influence the pressure drop in the annular space. As pointed out by Beck,[1] the control of this component of the total pressure drop may be of special importance where lost circulation problems are encountered. Other hydrodynamic problems to which it should be possible to apply measurements of the plastic flow properties include predictions of the velocity distribution in non-turbulent flow and the critical velocity for transition to turbulence.

Plastic viscosity and yield value, as absolute flow properties, will reflect the colloidal or surface-active behavior of the solids present in drilling fluids. Measurements of these properties should therefore find application in developing a better understanding of such behavior and in characterizing the type and condition of these solids. Garrison and ten Brink[5] have utilized multispeed viscometric data in this manner, although their measurements were not expressed in terms of the absolute flow properties.

In connection with the application of these measurements, it should be recognized that the presently used one-point viscosity measurements are relative in nature. The API Stormer 600-rpm measurement, for example, is a function of both plastic viscosity and yield value, as well as mud weight, and will often be misleading when its application to mud control problems is attempted.

NOMENCLATURE, UNITS, AND DEFINITIONS

In Fig. 1 an idealized plot is given of the flow variables involved in any viscometric measurement. It is seen that the flow behavior of plastic fluids is characterized by two constants — plastic viscosity, μ_p, and yield value, ϕ. Other workers have used the term rigidity for plastic viscosity or the term mobility for its reciprocal. The term plastic viscosity, however, emphasizes the close relation this property bears to the viscosity of a true fluid and is expressed in the familiar viscosity units of centipoises. The yield value is expressed in lbs/100 sq ft, the units adopted for gel strength measurements with the API shearometer.

Definitions of these properties based on rheological or macroscopic flow considerations follow from Fig. 1. The plastic viscosity of a substance obeying Bingham's equation is defined

[1]References given at end of paper.
Manuscript received in the office of the Petroleum Branch Aug. 12, 1950. Paper presented at the Petroleum Branch Fall Meeting in New Orleans, La., Oct. 4-6, 1950.

as the constant ratio of a given change in the shearing stress to the corresponding change in the rate of shear when the body is undergoing permanent deformation or flow. This same definition applies also to the viscosity of a true or Newtonian fluid. The yield value of a plastic substance may be defined as the difference between the shearing stress and the product of the plastic viscosity and rate of shear. If Bingham's law is obeyed at very low rates of shear, the yield value is also the shearing stress which must be exceeded for permanent deformation or flow to take place.

PLASTIC FLOW, PLUG FLOW AND THIXOTROPY

Several aspects of the plastic flow of drilling fluids deserve comment before proceeding to a description of the instrument used in the present work. First, at some low rotor speed (usually below 100 rpm in any practical viscometer), a curvature toward the origin will occur in the linear relationship between rotor speed and stator torque (see Fig. 1). This curvature, often referred to as the plug flow region, has been shown by Reiner and Riwlin,[2] in the case of a fluid obeying Bingham's equation, to begin when the yield value exceeds the shearing stress at the wall of the outer cylinder of a rotational viscometer. Thus, the phenomenon of plug flow is characteristic of and not a deviation from the behavior of a "Bingham body." It should be stated, however, that deviations from Bingham's law are to be expected in this low shear rate range in the case of systems, such as most drilling muds, which show highly time-dependent gel strength properties.

The existence of such time effects, generally referred to as thixotropy, introduces the second complication encountered in observations of the laminar flow behavior of drilling muds. Several workers[4] have proposed the use of "hysteresis loop" and "thixotropic level" concepts to characterize systems showing such effects. It has been observed by the authors, however, particularly in the case of highly chemically treated field muds, that equilibrium torque readings with a rotational viscometer may be reached in a matter of a few minutes, provided that each such reading is preceded by an equilibrium at a higher rotor speed. (At a constant rotor speed the torque will then increase toward the equilibrium value: the opposite occurs if the reading is preceded by an equilibrium at a lower speed, and somewhat longer times are involved). These observations indicate that the mud flow in field systems, in situations where a simple laminar type of flow is expected to prevail, may be very nearly at a steady state, as defined by equilibrium torque readings.

If characterization of the "thixotropic property" of the mud is desired, it is felt that this may be furnished by measurements of the increase in gel strength with increasing periods of rest time. Some of the complications which arise in obtaining such measurements have been discussed by Cardwell.[5] Slippage, probably caused by syneresis, may also be a serious problem when rest times of the order of 30 minutes or longer are involved. The authors believe that the usual techniques for avoiding these difficulties cannot be easily applied to instruments suitable for field measurement of the plastic flow properties defined above and that gel strength data can best be obtained with an instrument designed specifically for such measurements. Mud problems which require this type of rheological analysis include the prediction of bottom hole pressure surges developed by up and down swabbing and when breaking circulation, as well as the prediction of the ability of the mud to suspend cuttings on shutdown.

INSTRUMENT DEVELOPMENT

In plotting data obtained with a rotational viscometer according to the scheme of Fig. 1, *i.e.*, viscometer rotor speed (rate of shear) versus the torque on the stator (shearing stress), a straight line will result for a plastic and thixotropic fluid if two requirements are met: first, that the viscometer be run long enough at each speed to reach an equilibrium torque reading; and second, that the design of the viscometer rotor and stator be such that a strictly linear calibration relationship results, *i.e.*, kinetic energy and end effects are absent. (These effects also introduce a density dependence, as in the Stormer viscometer).

In addition to giving a straight-line plot of the observed data, a suitable viscometer should possess sufficient compactness, ruggedness, and simplicity of operation for use in the field as well as in the laboratory. Precision and reproducibility should be of the order of ±2 per cent.

A survey of rotational viscometers which were available commercially revealed that none of them completely filled the requirements set forth above. Experimentation with the Stormer viscometer, the rotational viscometer most commonly used in oil field work, indicated that it was unsatisfactory for adaptation to such purposes. One commercially available viscometer, the Fann V-G Meter,* met all of the desired requirements with the exception of the multispeed feature, so it was decided to alter this instrument accordingly. This viscometer, employing a motor-driven outer cylinder turning around a stator that could be balanced to a null point by means of suspended weights, had a number of very desirable features: compactness, a rugged bearing system, a 6-volt d.c. motor for use with an automobile storage battery, and a suitable rotor and stator design.

The multispeed control feature was obtained by substitution of a variable speed type CRX governor unit, made by the Lee Engineering and Manufacturing Co., Milwaukee, Wis., for the constant-speed governor supplied with the motor. It was necessary to lengthen the motor housing by about two inches in order to install a manually set cam-driven push-rod control

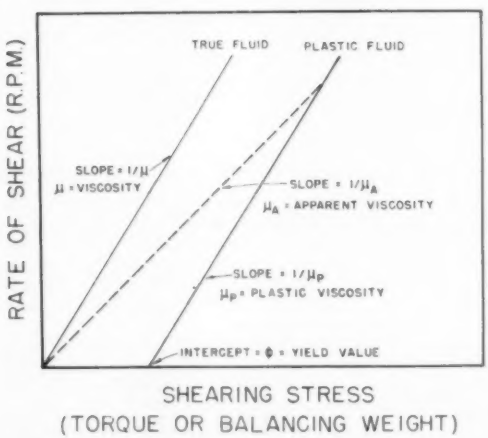

FIG. 1 — FLOW DIAGRAM FOR PLASTIC FLUIDS.

*Manufactured by the Geophysical Machine Works, Houston, Tex.

for the governor. By adjustment of this mechanism, rotational speeds of approximately 600, 500, 400, 300, and 200 rpm could be set, maintained, and duplicated.

Fig. 2 is a photograph of the instrument with the rotor partially immersed in a water-jacketed sample container. The disassembled stator and rotor are shown at the side of the instrument. A high speed switch on the left side of the gear housing operates a governor release mechanism, making available a top, uncontrolled speed of about 1,100 rpm. In order to obtain equilibrium torque readings, the mud sample is first sheared at this speed for about a minute, after which torque readings can be made at successively lower speeds. Usually, when making such a "down curve," the equilibrium torque will be reached in about the length of time required for adjusting the balancing weight.

CALIBRATION AND REPRODUCIBILITY

The calibration of a multispeed rotational viscometer for use with plastic fluids can best be accomplished with a series of true fluids of known viscosities. The test fluids used in calibrating the viscometer described above were glycerol-water solutions, the viscosities of which had been determined with Fenske-Ostwald capillary viscometers. A linear calibration relationship was found, indicating that kinetic energy and end effects were negligible as desired. This relationship is described by the equation:

$$\mu = \frac{AG}{Z} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where

μ = viscosity, centipoises
G = balancing weight (torque), gms
Z = rotor speed, rpm
A = calibration constant

The constant A determined from the calibration data may be compared with a theoretical value calculated from the dimensions of the viscometer by means of the Couette-Margules equation.

In the case of plastic flow the above variables are related by the equation:

$$\mu_p = \frac{AG - B\phi}{Z} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Since calibration fluids for plastic flow do not exist, the constant B must be determined from the little-known equation of Reiner and Riwlins[3] for the flow of a plastic fluid in a rotational viscometer, which gives

$$B = \frac{(100)\ (30/\pi)\ ln\ (r_c/r_b)}{(0.20886)} \quad \ldots\ldots\ldots (3)$$

where

r_c = radius of outer cylinder, cm
r_b = radius of inner cylinder, cm
$30/\pi$ = factor for converting from rad/sec to rpm
100 = factor for converting from poises to cp
0.20886 = factor for converting from dynes/cm^2 to lbs/100 sq ft

Equation (2) may conveniently be applied to the calculation of plastic viscosity and yield value from experimental data on drilling fluids if the data are plotted as in Fig. 1. Denoting the intercept on the balancing weight (torque) axis, where $Z = 0$, as G_m, and the weight reading at the highest speed available as G_{max}, Equation (2) may be solved as follows:

$$\mu_p = k_1(G_{max} - G_m) \quad \ldots\ldots\ldots\ldots (4)$$

$$\phi = k_2\ G_m \quad \ldots\ldots\ldots\ldots (5)$$

where

$k_1 = A/Z_{max}$
$k_2 = A/B$

The accuracy of the calibration constant A determined as described was ±1 per cent. In the case of routine measurements of mud, employing a procedure suitable for use in the field, there are two main factors other than the previous history of the sample which affect the reproducibility of results with a given instrument. The first is the technique of the operator, and the second is the judgment employed in drawing a straight line through the data on the rpm versus balancing weight plot. With reference to the first factor influencing reproducibility, tests were made on a series of 26 widely different laboratory-prepared muds, data on each mud being obtained independently by two or three operators. Results from these tests gave an average deviation from the mean of the two or three observations of about ±3 per cent for both plastic viscosity and yield value. Deviations resulting from different individuals plotting the data amounted to approximately 2 per cent for the plastic viscosity and 5 per cent for the yield value.

Deviations from linearity in the rpm versus balancing weight plot, *i.e.*, from ideal plastic flow at the rates of shear used, have been within the indicated accuracy of the method except in cases where solids are settling rapidly in the sample. However, in this event, valid viscosity measurements are impossible to make with any type of rotational viscometer.

EXPERIMENTAL RESULTS

In order to show how measurements of the plastic flow properties of muds, as obtained with the multispeed viscometer, may be utilized, the results of several laboratory investigations will be presented. The first investigation was carried out for the purpose of establishing relationships between the multispeed viscometric measurements and those now in com-

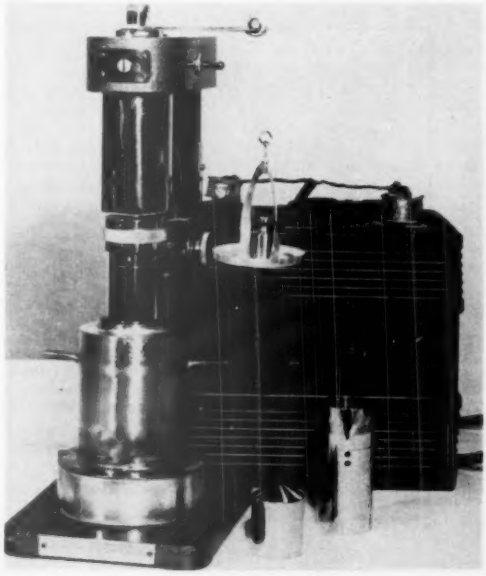

FIG. 2 — MULTISPEED VISCOMETER, FIELD MODEL.

mon usage, while the second was concerned with the response of the plastic flow properties to chemical treatment.

Relationships with Stormer Viscosity And Gel Measurements

Twenty-six muds prepared in the laboratory, and representing a variety of mud systems, were used in the first investigation. During the preparation and testing of each mud, special efforts were made to insure identical handling and measuring procedures, in order to minimize any variations which might be due to such factors; each measurement was checked by two or three operators. The correlations which were found between the various viscometric measurements are shown in Figs. 3, 4, and 5.

In the case of the correlation of the Stormer viscosity with the plastic flow properties (Fig. 3) and the Stormer-multispeed viscometer initial gel correlation (Fig. 4), straight-line relationships were found. As indicated in Figs. 3 and 4, these relationships are not greatly dependent on the mud system, except for the case of the salt-contaminated mud. The correlations of the initial and ten-minute gels and the initial shear strength with the yield value, on the other hand, resulted in power functions, which were affected by the type of mud system. The actual data are not shown in Fig. 5, since the average deviation from the plotted lines was of the order of 25 per cent.

Chemical Treatment Studies

In the investigation of the effect of chemical treatment on the plastic flow properties, a bentonite-kaolinite base mud containing about 30 weight per cent solids was prepared and treated with various quantities of quebracho, Calgon, and sodium acid pyrophosphate. Fig. 6 shows the effect of added quebracho on plastic viscosity, yield value, and Stormer viscosity. Similar curves were obtained for the phosphate treatments. It is seen that "viscosity reduction" by chemical treatment is accomplished entirely by a reduction in the yield value, while the plastic viscosity actually increases somewhat.

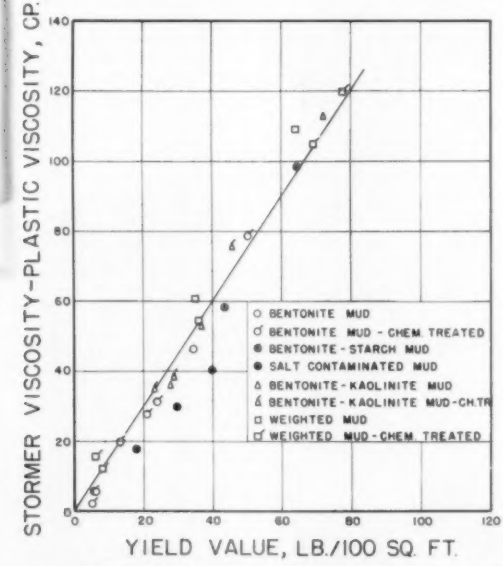

FIG. 3 — CORRELATION OF STORMER VISCOSITY WITH PLASTIC FLOW PROPERTIES.

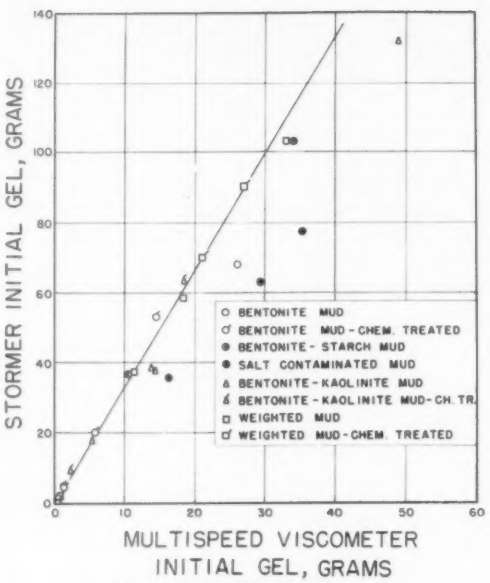
STORMER INITIAL GEL, GRAMS
MULTISPEED VISCOMETER INITIAL GEL, GRAMS
BENTONITE MUD
BENTONITE MUD - CHEM. TREATED
BENTONITE - STARCH MUD
SALT CONTAMINATED MUD
BENTONITE - KAOLINITE MUD
BENTONITE - KAOLINITE MUD - CH. TR.
WEIGHTED MUD
WEIGHTED MUD - CHEM. TREATED

FIG. 4 — CORRELATION OF INITIAL GELS.

Since the plastic viscosity of a mud is not reduced by chemical treatment, the higher the plastic viscosity/yield value ratio, the less is the susceptibility of the mud to chemical treatment. This concept is illustrated in Fig. 7, in which plastic viscosity is plotted against the yield value for a large number of muds which are available in the laboratory. The compositions of these muds fall into four groups, which may be described as follows:

(1) high-solids muds including bentonite-kaolinite systems, native clays, and salt-water clays

(2) bentonite-water muds

(3) high-solids muds containing three per cent bentonite and varying percentages of Gulf Coast shale

(4) alkaline-tannate-lime muds, representing samples over the entire mud weight range from 9.0 lb/gal (67.2 lb/cu ft) laboratory-prepared muds to 18 lb/gal (134.4 lb/cu ft) field muds. While some were starch muds, all had been treated with caustic soda, quebracho, and lime.

From Fig. 7 it may be seen that these groups give a family of curves corresponding to different susceptibilities to chemical treatment, as defined above.

DISCUSSION AND INTERPRETATION OF RESULTS

Correlation with Stormer Measurements

It is well known that any single point viscosity measurement on a plastic fluid, such as the Stormer 600-rpm reading, is actually an apparent viscosity, *i.e.*, a value equivalent to the viscosity of a true or non-plastic fluid giving the same observed stress reading as the plastic fluid at the particular rate of shear chosen (see Fig. 1). Thus, Equations (1) and (2) may

be combined to define such an apparent viscosity, μ_a, in terms of the plastic flow properties:

$$\mu_a = \mu_p + (B/Z)\,\phi \quad \ldots\ldots\ldots\ldots \quad (6)$$

This equation also shows that the apparent viscosity varies linearly with the reciprocal of the rotor speed, Z, as is illustrated by the data of Garrison and ten Brink[4] and Bednarski.[5] Where the apparent viscosity versus reciprocal rpm plots given by these workers are linear, it is indicated that the muds investigated obeyed the law of plastic flow.

The correlation of the Stormer viscosity, μ_s, with the plastic flow properties is shown in Fig. 3 to be of the form predicted by Equation (6) when μ_a is substituted for the apparent viscosity. The deviations of the data from a single relationship are smaller than would be expected from a consideration of the peculiarities of the Stormer design, such as a considerable density dependence due to kinetic energy and end effects and the opportunity for the existence of a non-flowing plug inside the rotor.

In the case of the Stormer-multispeed viscometer initial gel correlation (Fig. 4), a correlation of the expected form was also found. The proportionality factor was close to that calculated from the respective viscometer dimensions. The correlations of Figs. 3 and 4 may be used where approximate conversions from multispeed viscometer data to Stormer data are required.

The reason for the power functions obtained for the correlations of Fig. 5 is not known. When the Stormer initial gel strength values are converted to the units of lbs/100 sq ft, the data of Fig. 5 show that the initial gel strength and initial shearometer reading are both less than the yield value, all three measurements being expressed in the same units. This confirms previous reports[1] that at very low rates of shear Bingham's law is no longer followed. It is felt, however, that this fact does not constitute a limitation of the usefulness of measurements of the plastic flow properties with regard to those applications which were mentioned above, since the yield value measured by the present method, together with the plastic viscosity, determines the relationship between the rate of shear and shearing stress throughout most of the range of laminar flow.

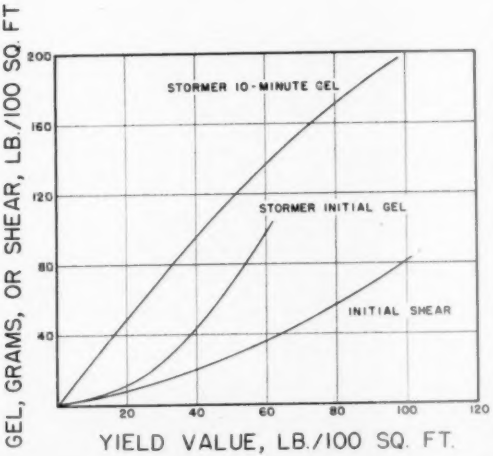

FIG. 5 — CORRELATION OF INITIAL AND 10-MINUTE GELS WITH YIELD VALUE.

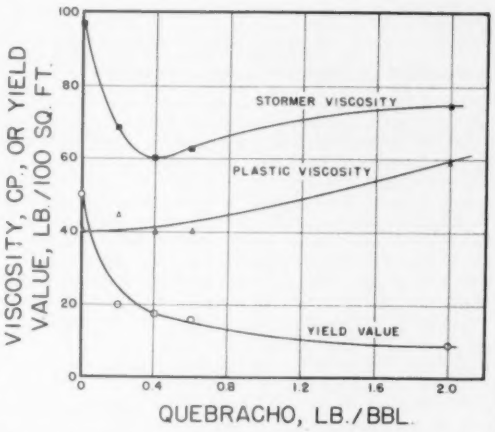

FIG. 6 — EFFECT OF QUEBRACHO TREATMENT ON BENTONITE-KAOLINITE MUD.

Application to Chemical Treatment

In developing explanations for the changes in plastic viscosity and yield value with addition of deflocculating agents, it is helpful to give a partial and limited interpretation of these two viscometric properties in terms of the colloidal or sub-microscopic structure of drilling muds. From the purely rheological definitions of these properties given above, it may be seen that in the case of a plastic fluid such as a drilling mud the frictional resistance to flow, measured by the shearing stress or viscometer torque reading, is composed of two parts (see Fig. 1). The first is proportional to the rate of shear and thus is largely the resistance to flow due to the mechanical friction of the particles.

Since the plastic viscosity is a measure of this proportionality, this property will be a function of solids concentration and shape, as predicted by an extension of Einstein's equation for the hydro-dynamic interaction effects of dispersed solids on the viscosity of a suspension.[7] If the particles carry an electric charge, the plastic viscosity might also be expected to increase with decreasing particle size, as described by Smoluchowski's modification of Einstein's equation. Since the action of deflocculating agents or "viscosity reducing" chemicals should not produce more symmetrical or larger particles, but rather the opposite, it would be expected that reduction of the plastic viscosity by such treatment would be difficult if not impossible. The observed increase in plastic viscosity (Fig. 6), on the other hand, can be explained as the result of dispersion of clay aggregates in the mud.

The second type of resistance to flow is independent of the shear rate and is due to the "gel forces" acting between the particles of the suspension. It is believed that both attractive and repulsive forces are operative, the latter originating primarily from the electrical charge carried by the particles. This component of the total resistance to flow is measured by the yield value, which may then be expected to be a function of the concentration of the mud solids and those factors, such as surface charge and potential, which affect the interparticle forces. Since deflocculating agents are thought to adsorb on the solid particles, thus altering the chemical nature of their surfaces and affecting the interparticle forces, the "viscosity reduction" due to such chemical agents should be almost

entirely the result of a decrease in the yield value, as is observed.

Application to Pressure Drop Calculations

One of the primary aims of chemical treatment of muds is, of course, to control the hydrodynamic behavior upon which several of the most important functions of muds are based. In this connection the plastic flow properties measured as described above may be used to predict pressure drops in certain cases of laminar flow. It should be noted that the Buckingham equation for pipe flow cannot be used to describe flow in an annulus, even if the equivalent diameter (four times the hydraulic radius) is substituted for the pipe diameter.[11] Drill pipe rotation will obviously cause further complications in the case of flow in a well annulus.

Another factor which is often overlooked is that if the temperature of the mud sample at the time of measurement is considerably different from average well conditions, corrections for the effect of temperature on the plastic flow properties should be made. In the case of water-base muds, the magnitude of the correction for the plastic viscosity may be estimated from the effect of temperature on the viscosity of water. Such a consideration indicates that for a difference of 80°F between the average well temperature and the temperature at which the mud is measured, the corrected plastic viscosity will be of the order of half the measured value. Since the slope of the apparent viscosity versus reciprocal rpm plot for a drilling mud is proportional to its yield value [see Equation (6)], the data presented by Bednarski[9] show that the effect of temperature on the yield value varies widely among different muds and in some cases the yield value at 160°F may be twice that at 80°F.

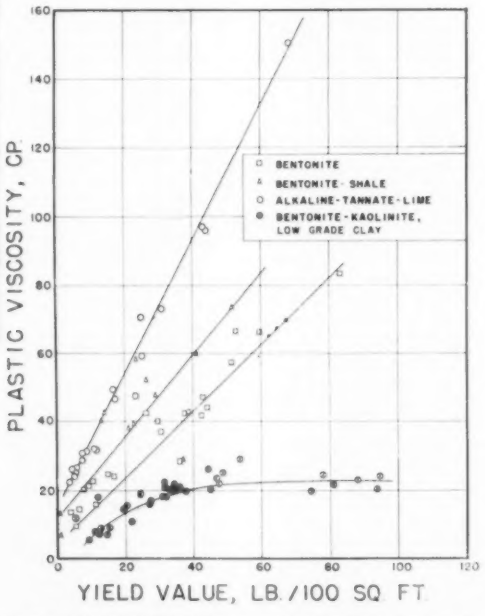

FIG. 7 — PLASTIC VISCOSITY-YIELD VALUE CORRELATION FOR VARIOUS MUD SYSTEMS.

These estimates of the effect of temperature have been applied to a pipe flow pressure-drop calculation for a mud of 20 cp plastic viscosity and 10 lbs/100 sq ft yield value, as measured at 80°F. The result was a pressure drop 60 per cent higher than that calculated from the measured properties.

CONCLUSIONS

1. A commercially available rotational viscometer modified to permit multispeed operation, has a straight-line calibration and is sufficiently rugged for field as well as laboratory use.

2. The behavior of water-base drilling fluids in this viscometer with few exceptions is described by the law of plastic flow, provided that equilibrium torque readings are obtained. The steady-state laminar flow behavior of muds is therefore characterized by the variables, plastic viscosity and yield value.

3. The measurements with the multispeed viscometer are approximately related to Stormer viscometer measurements by the following equations:

$$\mu_S = \mu_p + 1.5\ \phi$$
$$G_S = 3.3\ G_P$$

where

μ_S = Stormer 600 rpm viscosity, cp
μ_p = plastic viscosity, cp
ϕ = yield value, lbs/100 sq ft
G_S = Stormer initial gel, gms
G_P = multispeed viscometer initial gel, gms

4. The plastic flow properties may be interpreted in terms of the concentration and surface properties of the solids present in the mud. Such considerations can be used to explain the action of chemicals in "viscosity reduction" and suggest that the susceptibility of a mud to chemical treatment can be predicted from plastic viscosity and yield value data.

5. The pressure drop of a mud in laminar flow, *e.g.*, in a well annular space, will depend on the plastic flow properties. In order to make pressure drop calculations, knowledge of the effect of temperature on the plastic flow properties is required, since the yield value at average well temperatures may be considerably greater than that measured at the surface.

ACKNOWLEDGMENT

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A MODIFIED LOW-STRENGTH CEMENT

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ABSTRACT

The need for a low-strength cementing composition for use in well cementing is reviewed and results are presented of laboratory and experimental field tests of a modified cement having a controlled ultimate tensile strength of approximately 200 psi. The modified cementing composition may be prepared from either high early strength or normal portland cements by the addition of bentonite clay and a suitable agent for dispersing and controlling the set of the slurry. Substitution of the modified cement for conventional slow-set cements may give better completion results in many wells because the modified cementing composition has lower set strength, lower slurry density, and greater slurry stability than conventional cement slurries. The lower ultimate strength allows greater penetration with less shattering of the set cement when perforating casing and cement. The lower slurry density allows the placement of longer columns of cement slurry, and the greater slurry stability reduces the possibility of having an uncemented section caused by the settling of cement particles before the cement sets.

INTRODUCTION

High strength has always been one of the accepted criteria of a good cement. During the early use of portland cement in well cementing, emphasis was placed upon securing cements with higher strengths. In 1931, Barkis[1] reported that, "Normal oil well cements have been improved to develop greater strengths and uniformity of product, which has aided in producing successful jobs in cementing the deeper strings."

As long as most wells were completed by the open-hole method, the use of cements having high strengths seemed desirable, and there was no objection raised against high-strength cementing compositions. For a number of years, however, the industry has been completing a large number of wells by setting and cementing casing through productive horizons and then obtaining production by gun-perforating the section of casing opposite the desired interval. Although this method has been generally successful, difficulties have been experienced in some cases in completing or recompleting wells because of apparent lack of adequate penetration by the bullets through the casing and surrounding sheath of cement and into producing formation. In addition to the penetration trouble, there have been indications that fracturing and shattering of the set cement by perforating might be a contributing factor in causing the failure of some jobs to exclude water or gas from oil producing zones. The possibility that cements having high set strengths were contributing to the difficulty in obtaining satisfactory perforating results has received attention during recent years. Gun perforating tests conducted in 1944 showed that the depth of bullet penetration into set cement varied with the hardness of the cement, the greater the strength of the cement the less being the penetration. In 1946, Farris[2] pointed out that high strength cements were not needed in well cementing, and in 1947, data published by Oliphant and Farris[3] showed that set cement was perforated without shattering at approximately 150 psi tensile strength, whereas at approximately 300 psi tensile strength severe cracking and shattering occurred. Oliphant and Farris suggested that wells be perforated at the proper time interval after placement of the cement so that the set cement would have the desired strength.

Several difficulties may be encountered in trying to perforate a cement job at the correct time to catch the tensile strength near 150 psi. The rate of strength development of different cements varies considerably. This fact is illustrated by results of tensile strength measurements presented in Fig. 1. These data show that at 175°F the tensile strengths of three conventional slow-set cements varied from 75 to 235 psi at the end of 12 hours. After 24 hours, the tensile strengths varied from 200 to 455 psi. The rate of strength development is affected, also, by the temperature of the formation, and this adds to the uncertainty of perforating at the correct time, since accurate well cementing temperatures may not be known in many cases. Furthermore, in the recompletion of wells it is sometimes necessary to perforate cement which has set for a long period and has developed maximum or final strength.

In view of the apparent need for a cementing composition having a controlled ultimate strength, an investigation was

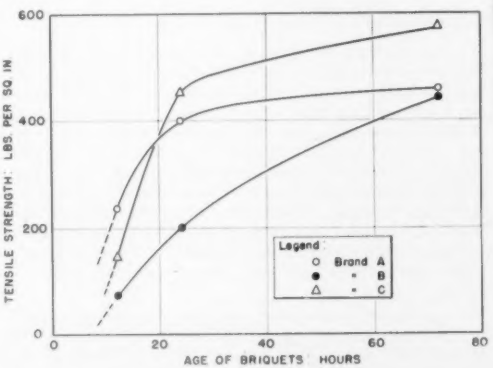

FIG. 1 — STRENGTH DEVELOPMENT OF THREE CONVENTIONAL SLOW-SET CEMENTS CURED UNDER WATER AT 175°F.

[1]References given at end of paper.

Manuscript received in the office of the Petroleum Branch Aug. 17, 1950. Paper presented at the Petroleum Branch Fall Meeting in New Orleans, La., Oct. 3-6, 1950.

Table I — Physical Properties of Modified Low-Strength Cements

	Modified High Early Strength[1]	Modified Normal Portland[2]
Water to cement ratio, gal per sack:	10	9
Pumpability Time, hrs: Halliburton Consistometer at atmos. pres.:		
Temp. of Test: 150°F	4½	—
Temp. of Test: 175°F	4¼	4¼
Temp. of Test: 200°F	3¼	—
Well Simulation Tests:[3]		
Schedule 5 (8,000 ft)	2⅔	3
Schedule 6 (10,000 ft)	2	2¾
Schedule 7 (12,000 ft)	1½	2¼
Schedule 8 (14,000 ft)	1⅓	1-11/12
Schedule 9 (16,000 ft)	1⅙	1⅔
Schedule 10 (18,000 ft)	1⅙	1⅓
Tensile Strength, psi:		
Cured under water at 150°F		
Age of Briquets: 12 hrs	65	—
Age of Briquets: 1 day	125	—
Age of Briquets: 3 days	190	—
Cured under water at 175°F		
Age of Briquets: 12 hrs	135	—
Age of Briquets: 1 day	175	154
Age of Briquets: 3 days	185	—
Age of Briquets: 7 days	198	198
Cured under water at 200°F		
Age of Briquets: 12 hrs	155	—
Age of Briquets: 1 day	160	—
Age of Briquets: 3 days	210	—
Wet Permeability, md:		
Cured under water at 175°F		
Age of Test Specimen: 1 day	0.05	0.11
Age of Test Specimen: 7 days	0.004	0.005

[1]A high early strength cement with 15 lb. of bentonite and 0.5 lb. of calcium lignosulfonate added per sack of cement.
[2]A normal portland cement with 15 lb. of bentonite and 0.5 lb. of calcium lignosulfonate added per sack of cement.
[3]According to API Code 32.

initiated several years ago in an attempt to develop such a composition.

LABORATORY INVESTIGATION OF MODIFIED CEMENT

Composition

The set strength of cement is reduced by an increase in the water-to-cement ratio of the slurry; however, the cement particles in high water-to-cement ratio slurries settle out, allowing a water-cement separation to occur.[4,5] This sedimentation of high water-to-cement slurries may be avoided by the addition of bentonite clay.[6] Hence, it appeared that a stable cementing composition with a controlled ultimate set strength might be produced by using the correct amount of mix water to prepare a slurry of portland cement and bentonite clay. However, laboratory tests revealed that the addition of a small amount of a dispersing agent was needed to disperse the mixture of cement, clay, and water, and to allow adjustment of the set time.

It was found by laboratory tests that a cementing composition with an ultimate tensile strength of approximately 200 psi could be prepared by adding 12 - 15 lb bentonite clay and approximately 0.5 lb calcium lignosulfonate per sack of high early strength cement, and using enough mix water to make a slurry with a water-to-cement ratio of about 10 gal per sack. Additional tests also showed that a satisfactory modified cementing composition could be prepared from normal portland cement by the addition of the same quantities of bentonite clay and calcium lignosulfonate, but with the addition of enough mix water to make a slurry with a water-to-cement ratio of about 9 gal per sack.

Pumpability, Strength and Permeability

A satisfactory well cementing composition must retain its fluidity long enough to be pumped into place, then it must develop sufficient strength and impermeability to form an effective seal within a reasonable length of time. These properties may be evaluated in the laboratory by pumpability, tensile strength, and permeability tests. The results of such tests of modified low-strength cements are presented in Table I. For comparison, similar laboratory data for three conventional slow-set cements are presented in Table II. The pumpability times of the modified cement slurries were found to be about the same as the pumpability times of the conventional slow-set cement slurries, and the permeability of the set modified cements, although greater than the permeability of the conventional cements, was considered to be sufficiently low to make a good seal. The 7-day tensile strengths of the modified cements were approximately 200 psi, whereas the 7-day tensile strengths of the conventional cements varied from 398 to 667 psi. The modified cement developed most of its strength within the first 24 hours.

These data indicated, therefore, that for the cementing of many wells either high early strength or normal portland cement containing bentonite clay and calcium lignosulfonate could be substituted for existing slow-set cements.

Perforating Properties

Since the modified low strength cement was developed in an attempt to obtain better perforating results through cemented casing, the depth of penetration into conventional and modified cements by both bullet and jet perforators was determined in aboveground setups prepared by placing the test cement slurries in the annulus formed by positioning casing inside a 55-gal barrel. In order to make the test more severe, two strings of pipe were used in two of the setups prepared with modified cement. In these two assemblies, the entire volume of the 55-gal barrel, excluding the inside of the smaller pipe, was filled with modified cement slurry. After the cement slurries had set long enough to develop most of their strength, the casing was perforated and the penetration and fracturing of the set cements were observed. The results of these perforating tests, presented graphically in Fig. 2, are summarized below. The results shown in the following table represent the average penetration of all perforations which lodged within the set cement. Perforations which passed completely through the test setups were not considered in compiling the data in this table.

Comparative Penetration into Conventional and Modified Cements

Type of Perforator	Pipe Used in Tests	Total Penetration, in. Conventional Cement	Modified Cement
Bullet Gun No. 1	5½" - 15# J-55 Csg.	11/16	4-1/16
Bullet Gun No. 2	5½" - 17# N-80 Csg.	2-1/4	——
Bullet Gun No. 2	5½" - 17# N-80 Csg. inside of 9⅝-32.3# H-40 Csg.	——	5-7/16
Jet Gun	5½" - 17# N-80 Csg.	6-3/4	——
Jet Gun	5½" - 17# N-80 Csg. inside of 9⅝-32.3# H-40 Csg.	——	10-1/2

These tests showed that penetration by either bullet or jet was better through casing cemented with modified cement than it was through casing cemented with conventional cements. Also, very little or no fracturing of the set modified cement was caused by perforating, whereas quite severe fracturing of the conventional cements was evident in some of the surface tests. These results indicated that substitution of modified cement for conventional cements offered a method of obtaining better production in areas where difficulty is experienced in obtaining satisfactory penetration of the casing and the surrounding sheath of set cement. It also appeared that the modified cement might form a more effective seal than conventional cements, since perforation of the set modified cement did not cause fracturing.

Although better penetration by perforation was the primary objective in the development of the modified cement, there are two properties of the modified cement slurry which are not found in existing conventional cement slurries and which may be advantageous in the cementing of wells. One is greater slurry stability and the other is lower slurry density.

Slurry Stability

The modified cement slurry remains in suspension until it sets, whereas slurries of conventional slow-set cements settle out before they set, allowing a water-cement separation to occur. This property is illustrated by the data presented in Fig. 3, which show that slurries of the modified cement set to a volume approximately equal to the original slurry volume. On the other hand, a layer of clear water collected above conventional slow-set cement slurries before they set. It is possible that in some cases a considerable portion of the vertical distance behind the casing in a well may be void of set cement when a conventional slow-set cement is used. When casing is cemented with a cement slurry which settles out before it sets, any irregularity in the diameter of the hole may allow bridging of the cement particles and cause an uncemented section to occur immediately below the bridge point. If this occurs, the cement job may fail to seal off the formations at a critical interval. This possible cause of cementing failure may be avoided by use of the modified cement.

Slurry Density

The modified cement containing 12-15 lb of bentonite and 0.5 lb calcium lignosulfonate per sack of cement produces a slurry with a density of approximately 13½ lb per gal at a water-to-cement ratio of about 10 gal per sack, whereas conventional slow-set cements produce neat slurries with a density of approximately 16 lb per gal at a water-to-cement ratio of about 5 gal per sack. The lower density of the modified cement slurry allows the placement of long columns of cement slurry in areas where formations will not support long columns of heavier conventional cement slurries. This property is particularly valuable in those cases in which there is danger of losing circulation in the interval to be cemented.

FIELD USE

In order to explore the utility of the modified cement and the problems connected with its use, arrangements were made for field use of the modified cement on an experimental basis. Thirty-five field jobs had been completed at the time of the writing of this paper. Twenty-one of these jobs were performed to cement the production string of casing for original completions. The other fourteen jobs were performed in working over old wells, five of which were liner jobs and nine of which were squeeze jobs. A brief discussion of each type job is presented below.

Cementing of Production String

Of the 21 jobs in which the modified cement was used to cement casing for the original completion, 18 jobs were performed in an attempt to evaluate the possible advantage of a low density slurry in the placement of a long column of cement slurry in areas where weak formations fail to support a long column of conventional cement slurry. Sixteen of these jobs were performed in wells located in Coke and Runnels counties, Tex. One well was located in Marion County, Miss., and one was in Jefferson Davis County, Miss. On several jobs performed in these areas with the use of conventional cement, returns were lost during the placement of the cement slurry. When this happened, it was necessary to perforate the casing and perform a second cement job in order to obtain adequate fill-up around the casing. Often several cement jobs were necessary before the weak formation was sealed and the desired fill-up was obtained. This procedure is time-consuming and expensive. It was thought that the lower density of the modified cement slurry would allow the placement of sufficient slurry to seal off all the troublesome zones by the primary cement job. Temperature surveys after cementing with modified cement showed that adequate fill-up had been obtained in 17 of the 18 wells. In the case of the one

Table II — Physical Properties of Conventional Slow-Set Cements

	Brand A	Brand B	Brand C
Water-to-cement ratio, gal per sack:	4½	4½	4½
Pump Time, hrs., Halliburton Consistometer at atmos. pres.:[1]			
Temp. of Test: 140°F	7	5-1/12	8½
Temp. of Test: 160° F	7⅙	4⅓	7⅓
Temp. of Test: 180°F	9⅗	4	6⅙
Temp. of Test: 200°F	4¼	2¾	4
Well Simulation Tests:[1,2]			
Schedule 5 (8,000 ft)	4-5/12	4	5
Schedule 6 (10,000 ft)	3½	2-5/12	4
Schedule 7 (12,000 ft)	2-5/12	1-11/12	2⅙
Schedule 8 (14,000 ft)	1⅙	1½	1½
Schedule 9 (16,000 ft)	1-1/10	1⅙	1⅓
Schedule 10 (18,000 ft)	1	1-1/12	1⅙
Tensile Strength, psi:[1,2]			
Cured under water at 140°F			
Age of Briquets: 1 day	352	203	368
Age of Briquets: 2 days	453	300	492
Age of Briquets: 7 days	535	455	617
Cured under water at 160°F			
Age of Briquets: 1 day	358	233	357
Age of Briquets: 2 days	478	308	508
Age of Briquets: 7 days	500	398	603
Cured under water at 180°F			
Age of Briquets: 1 day	377	302	457
Age of Briquets: 2 days	490	403	610
Age of Briquets: 7 days	507	593	667
Wet Permeability, md:			
Cured under water at 175°F			
Age of Test Specimen: 1 day	0.002	0.026	0.009
Age of Test Specimen: 7 days	<0.001	<0.001	<0.001

[1]Data obtained and furnished by Petroleum Engineering Division Service Laboratory, Humble Oil and Refining Co.
[2]According to API Code 32.

well in which fill-up was not satisfactory, full returns were obtained throughout the cementing operations, but the top of the cement was not as high as desired. It appeared that in this case an insufficient volume of cement slurry was used.

The cementing of Sallie Odom D-1, Runnels County, Tex., was typical of the 17 jobs which were completed successfully:

After 9⅝-in. surface casing was set at 363 ft, 7⅞-in. hole was drilled to 5,294 ft and 5½-in. casing was cemented at 5,291 ft with 650 sacks of modified cement. A temperature survey after cementing located the top of the cement at 1,120 ft, which indicated that the cement job was satisfactory, since no troublesome zones were believed to exist above that point. The well was completed satisfactorily by the open-hole method.

Three of the 21 primary cement jobs were done in an effort to evaluate the possible advantage of a low-strength set cement in obtaining better perforating results through the production string of casing and the surrounding sheath of cement. Production after perforating the casing indicated that a good primary cement job had been obtained in all three jobs. Interesting results obtained on Seeligson C-126, Kleberg County, Tex., are described below.

After 9⅝-in. surface casing was set at 2,002 ft, 8⅝-in. hole was drilled to the total depth of 7,200 ft and 5½-in. casing was cemented with 660 sacks of modified cement. Rotowall type scratchers were attached to the casing from 7,090 to 7,100 ft and from 7,105 to 7,125 ft. Clear salt water was produced through 24 bullet perforations from 7,112 to 7,116 ft. Ninety sacks of conventional cement slurry were squeezed through these perforations. The surface breakdown pressure was 4,300 psi and the squeeze pressure was approximately 5,000 psi. Afterwards, the well produced clean oil with a low gas/oil ratio through perforations from 7,093 to 7,101 ft. The behavior of the squeeze job indicated that a good seal between the casing and the formation had been obtained with the primary cement job. Also, the production of clean oil through perforations just 11 ft above previous perforations through which clear salt water was produced indicated that the seal was not destroyed by perforation.

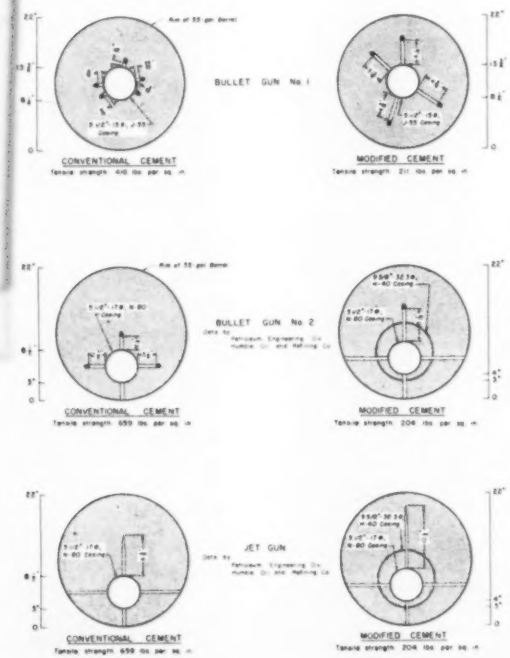

FIG. 2 — COMPARATIVE PENETRATION INTO CONVENTIONAL SLOW-SET AND MODIFIED LOW-STRENGTH CEMENTS.

Cementing of Liner

Modified cement was used to cement liners in working over five wells which had been completed originally by the open-hole method. After several years of production, the gas/oil ratio of these wells became excessively high and it was thought that this condition might be corrected by setting liner in the open hole and obtaining production through perforations in the liner. All these jobs were done on wells in the Means Field, Andrews County, Tex. A typical job on J. S. Means 20 is described below.

This well was completed originally by setting 5½-in. casing at 4,183 ft with 7¾-in. open hole to 4,532 ft, and acidizing the open hole. Since the open hole was drilled originally to a diameter of 7¾ in. and probably contained enlarged sections, it was thought that the well could be recompleted more readily by perforating through the liner and set cement if modified cement were used instead of conventional cement. The workover job was done, therefore, by setting 4-in. liner in the open hole with the modified cement, jet-perforating the liner, and acidizing the formation through the perforations. After the workover job was completed, the well was able to make its unpenalized allowable with a gas/oil ratio below 1,500 cu ft per bbl. The results indicated that the liner was cemented successfully with the modified cement and that satisfactory oil production was established through perforations in a fairly thick sheath of cement.

Squeeze Cementing

One of the nine squeeze cement jobs was done in order to obtain a set cement which could be readily perforated even though a thick sheath of set cement surrounded the casing. Since this well, J. H. P. Davis 23, Fort Bend County, Tex., had produced a large amount of sand, it was probable that the section surrounding the perforated casing was enlarged. After the squeeze job, satisfactory production was obtained by gun-perforation of the original producing interval against which the modified cement slurry had been squeezed.

The other eight squeeze jobs were done in an attempt to shut off either water or gas production in wells which were producing through perforated casing. In each case cement slurry was squeezed through the existing perforations and the casing was reperforated. Most of these jobs were done in attempts to shut off water production, and the casing was reperforated in either the same interval or slightly higher in the same producing zone. A typical job of this type, performed on the Kenedy Jr. B-6, Kenedy County, Tex., is described below.

This well was producing oil and a small amount of salt water through perforations from 6,922 to 6,926 ft when the water production increased from 2 per cent to 80 per cent within an interval of one month. Ninety sacks of modified

cement slurry was squeezed through these perforations with a final surface squeeze pressure of 3,300 psi. After the casing was jet-perforated from 6,915 to 6,925 ft, the well flowed approximately 65 per cent oil, 35 per cent salt water. The results on this workover job were inconclusive, since it was impossible to determine whether the squeeze job failed to seal off the water or whether the interval perforated contained water.

Although the use of modified cement seemed advantageous in squeeze cementing a well which contained an enlarged section in the producing interval, no definite advantage was evident in ordinary squeeze cement jobs performed to shut off either gas or water production.

In all the field jobs performed to date, no difficulty in the placement of the modified cement slurry and no failure attributable to the cement itself has occurred except on one squeeze job. During this squeeze job, it was impossible to pump the excess cement slurry out by reverse circulation. Regular circulation (long way) was established, but the retrievable tool became lodged in the casing during its removal. Inadequate mixing of the dry cement, clay, and lignosulfonate may have caused the cement slurry to set faster than expected, but other factors may have been responsible for the difficulty. The exact cause of the trouble was not identifiable.

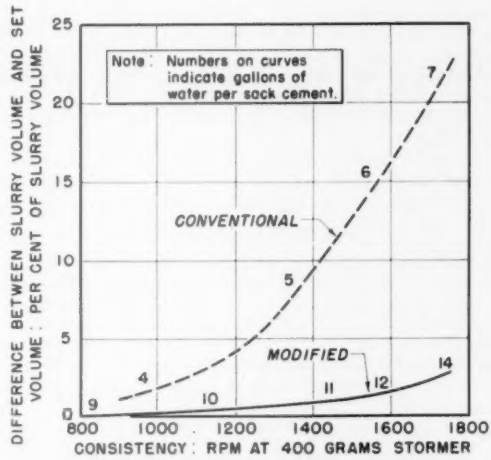

FIG. 3 — TREND OF SEDIMENTATION OF MODIFIED LOW-STRENGTH AND CONVENTIONAL SLOW-SET CEMENT SLURRIES.

MIXING, COMPOSITION AND COST OF MODIFIED CEMENT

The mixing of the three dry constituents — normal portland cement, bentonite clay, and calcium lignosulfonate — was done at bulk-cement plants. For the field jobs performed to date, the clay and lignosulfonate were added separately as the cement was transferred from railroad cars to bulk-cement trucks. In most cases, the mixing has been fairly satisfactory but it has required close supervision. Better mechanical facilities for the dry mixing are needed in order to assure proper mixing of the dry constituents without excessive supervision.

The modified cement tends to lump and to form a very thick slurry which appears to be poorly mixed; however, the agitation which occurs as the slurry passes through the pumps is sufficient to deliver a well-mixed slurry into the borehole. Slurry samples obtained from the line between the discharge of the pumps and the wellhead are smooth and lump-free even though the slurry in the sump tub is very lumpy. A smooth slurry relatively free of lumps in the sump tub is desirable, however, because it facilitates the weighing of the slurry and the judging of the slurry consistency and density by visual observation. On several field jobs, a small mechanical mixer in conjunction with the usual jet mixer has given smooth, lump-free slurries in the sump tub. Also, certain improvements to jet mixers have resulted in more satisfactory mixing of the modified cement slurry.

Observations of the first few field jobs indicated that slurries prepared in the field were thicker than slurries prepared in the laboratory. This was probably due to the difference in slurry mixing. In order to find the optimum bentonite clay concentration for field use, the clay content was varied from 9 to 14 lb per sack of cement on several succeeding field jobs. These results indicated that the modified cement slurry possessed the desirable consistency when the clay content was about 12 lb per sack of cement; therefore, most of the field jobs have been performed with 12 lb of clay per sack of cement. Variations in the lignosulfonate content have ranged from 0.3 to 0.6 lb per sack of cement; however, the lignosulfonate content has been near 0.5 lb per sack of cement for most of the field jobs. On several field jobs, chopped cellophane was added to help combat any tendency to lose slurry to weak formations. The water-to-cement ratios of the slurries have varied from about 9 to 12 gal per sack with slurry densities from approximately 13.7 to 12.7 lb per gal, respectively.

The cost of materials to prepare a given volume of modified cement slurry is at present about 15 to 20 per cent less than the cost of materials to prepare the same volume of conventional slow-set cement slurry. With cement at $1.10 per sack, bentonite clay at $1.75 per 100 lb, and calcium lignosulfonate at $12.00 per 100 lb, materials for preparing one cu ft of modified cement slurry with a water-to-cement ratio of 10 gal per sack cost $0.75. In comparison, 1 cu ft of regular neat cement slurry with a water-to-cement ratio of 5 gal per sack costs $0.96. This comparison does not include the cost of mixing the bentonite clay and calcium lignosulfonate with the cement.

CONCLUSIONS

1. The results of laboratory-scale tests show that a modified low-strength composition having pumpability and permeability properties satisfactory for well cementing may be prepared by the addition of clay and a dispersing agent to normal portland cement. The slurry has lower density and better stability than conventional cement slurries. The set modified cement is more readily penetrated by bullets or jets than is conventional cement.

2. The results of field tests indicate that the low density of the modified cement slurry is advantageous in the cementing of casing through zones in which there is danger of losing circulation with higher density slurries of conventional cement. This property of the modified cement slurry has apparently eliminated in some cases the time and expense of the stage cementing which would have been necessary with the use of conventional slurries.

3. The results of field tests indicate that the greater ease of penetration of the modified cement may be helpful in assur-

ing the perforation of fairly thick cement sheaths, and in preventing loss of seal due to shattering of the cement.

4. The results of field tests indicate that the modified cement has no particular advantage over conventional cement in squeeze cementing operations, unless the cement is to be squeezed into an enlarged hole section and subsequently perforated.

5. The relatively low cost of materials for the modified cement offers an economic advantage over the cost of conventional cement.

ACKNOWLEDGMENT

The authors wish to express their appreciation to R. A. Salathiel for his thoughts and efforts during the early development of this work, to G. E. Cannon for his help in arranging the field jobs and to Humble Oil and Refining Co.'s division and district personnel who conducted the field jobs. Appreciation is also extended to the management of Humble for permission to publish this paper.

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DISCUSSION

By W. C. Goins, Jr., Gulf Oil Corp., Houston, Tex.

The authors of the paper are certainly to be complimented on their interesting and well prepared paper, and on their valuable contribution to the technique of oil well cementing. I feel that due to the economies and low slurry densities afforded by the modified cements that we shall eventually see a rather extensive use of these materials. This should be particularly true in those areas where trouble is experienced in obtaining a satisfactory "fill-up" during casing cementing.

I have been associated with some recent laboratory experimental work with modified cements of the same and similar compositions as that of the authors. I would like to state that the results of this work verifies the authors' contentions that cements of this composition satisfy requirements as to strength, pumpability, and stirring time. I think it should be emphasized that although the modified cements as described are prepared from standard portland cement, they exhibit stirring times which make them comparable to slow-set cements. This is due not only to the increased water-cement ratio used, but also to the strong retarding action of the calcium lignosulfonate.

Recently laboratory tests were made of modified cement slurries prepared from two different brands of portland cements. Stirring of the slurries was continued while the temperature and pressures were increased at a rate designed to simulate the conditions of cementing in average Gulf Coast wells. The stirring time to 100 poises viscosity was then taken as the pumpable time of the slurries. These tests were made in a Stanolind Super-Pressure Thickening Time Tester in accordance with the methods of simulating casing setting operations as set forth in the API *Code for Testing Cements Used in Wells.* They showed that at a depth of 10,000 ft cements of a composition near that described had a pumpable time of from one to one and one-half hours in excess of that required to mix and displace 300 sacks of cement to that depth during casing setting. Increasing the calcium lignosulfonate to 0.6 per cent gave slurries which were pumpable for as long as any of four slow set cements in 10,000 and 14,000 ft simulated casing cementing tests where the slow set cements were prepared as normal 40 per cent slurries. I think this indicates that the use of the modified cements need not be confined to those shallow depths at which portland cements are normally employed.

One question which undoubtedly would be raised elsewhere, if not here, is whether the slow set cements could be used to prepare modified cements, in which case it might be assumed that the calcium lignosulfonate could be omitted. Our own experience, though somewhat limited in scope, indicates that it would be somewhat questionable. With one slow-set cement made up as a modified product, the use of 10 per cent bentonite seemed to completely destroy the slow-setting properties. With two other slow-set cements pumpability tests of modified slurries indicated that they might be used, but with another the slurry pumped for an excessively long period of over 8 hours in simulated deep well tests. These tests were made in a super-pressure consistometer, as described before, and without any added calcium lignosulfonate.

Since these tests indicated erratic performance of the slow-set cements when made into slurries of the modified type, and since all of the portland cements tested gave consistent results, it was felt that regular portland cement should be used. Also, the cost of the lignosulfonate, plus the cost of mixing it into the dry cement, is less than the difference in price between portland and slow-set cements. I should like to ask the authors whether slow-set cements should be used for the purpose of making modified cements of the type they have described.

AUTHORS' REPLY TO MR. GOINS

We wish to thank Goins for his pertinent remarks and for emphasizing that modified cements prepared with normal portland cements, bentonite clay, and calcium lignosulfonate possess suitable pumpability properties for use in deep wells.

In answer to the question about the use of conventional slow-set cements to prepare modified cements of the type described in the paper, our experience has been about the same as the experience which you reported. Early in our investigation, we found that the pumpability time of slow-set cements containing large percentages of bentonite clay varied considerably from brand to brand. We did very little work, therefore, in an effort to produce a high bentonite content cement slurry using slow-set cements. Instead, most of our work was done with high early strength and normal portland cements. We found that the pumpability time of slurries prepared with high early strength or normal portland cement, bentonite, and calcium lignosulfonate varied little from brand to brand. We found, furthermore, that the pumpability time could be extended by increasing the concentration of calcium lignosulfonate, thereby affording a means of controlling the pumpability time of the slurries.

In summary, it appears that some brands of slow-set cements may be suitable for producing high bentonite content cement slurries, while other brands may not be suitable for this purpose. ★ ★ ★

T.P. 3096

AN ANALYSIS AND THE CONTROL OF LOST CIRCULATION

GEORGE C. HOWARD, MEMBER AIME, AND **P. P. SCOTT, JR.,** STANOLIND OIL AND GAS CO., TULSA, OKLA.

ABSTRACT

During the drilling of wells, fractures which are created or widened by drilling fluid pressure are suspected of being a frequent cause of lost circulation. A study of the variables which are believed by the authors to be related to fracturing led to the premise that the presence of an effective lost circulation material in a drilling mud stream would serve to plug small fractures at the moment they are encountered or created and thereby eliminate a possible cause of lost circulation by preventing fluid pressure from widening and extending the fractures.

A large number of lost circulation materials were classified and tested in simulated fractures and in shallow wells. Granular type materials with a gradation of particle sizes were found to be the most effective for plugging. Within the limits of pumpability, the concentration in mud of each lost circulation material tested was found to be a controlling factor in determining the maximum size fracture which could be sealed. A new type centrifugal sorter was given preliminary tests and found to be capable of concentrating cuttings for rejection and reclaiming lost circulation materials.

[1]References given at end of paper.

Manuscript received in the office of the Petroleum Branch Feb. 19, 1951. Paper presented at the Annual Meeting of the AIME in St. Louis, Mo., Feb. 19-21, 1951.

INTRODUCTION

The control and prevention of lost circulation of drilling fluids is a problem frequently encountered during the drilling of oil and gas wells.

Lost circulation or lost returns may be defined as the loss to formation voids of the drilling fluids or cement slurries used in the process of rotary drilling and well completion. The loss may vary from a gradual lowering of mud level in the pits to a complete loss of returns. Not to be confused with lost circulation is the continuous reduction in mud volume caused by the loss of the fluid phase of muds as filtrate and the solid phase as filter cake during the continuous filtration process which occurs on permeable formation surfaces.

The loss of drilling fluids and their costly constituents is only one of the detrimental effects experienced when circulation is lost. The loss of drilling time, plugging of potentially productive formations, stuck drill pipe, blow-outs, excessive inflow of water, and excessive caving of formations are other effects which contribute to make the control and prevention

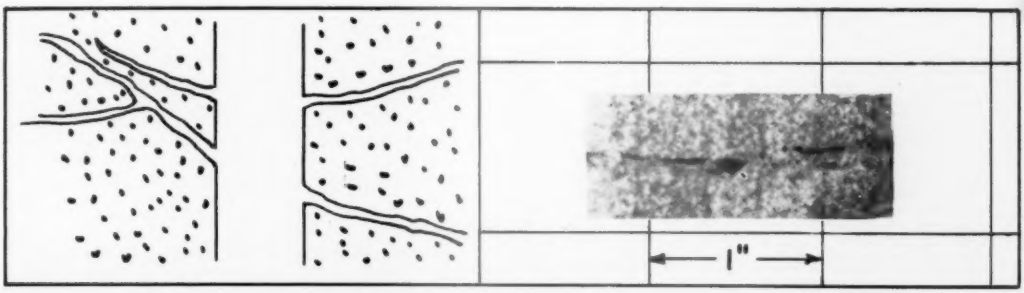

FIG. 1 — NATURAL OR INTRINSIC FRACTURES.

Table I — Identifying Features

Natural Fractures	Induced Fractures	Cavernous	Unconsolidated Formations
1. May occur in any type rock.	1. May occur in any type rock, but would be expected in formations with characteristically weak planes such as shale.	1. Normally confined to limestone.	1. Gradual lowering of mud level in pits.
2. Loss is evidenced by gradual lowering of mud in pits. If drilling is continued and more fractures are exposed, complete loss of returns may be experienced.	2. Loss is usually sudden and accompanied by complete loss of returns. Conditions are conducive to the forming of induced fractures when mud weight exceeds 10.5 lb/gal.	2. Loss of returns may be sudden and complete.	2. Loss may become complete if drilling is continued.
	3. Loss may follow any sudden surge in pressure.	3. Bit may drop from a few inches to several feet just preceding loss.	3. Since it is known that the rock permeability must exceed 100 darcys before mud can penetrate and that oil or gas sand permeability seldom exceeds 3.5 darcys, it is improbable that loose sands are ever the cause of mud loss to an oil or gas sand unless the loss can be attributed to the ease with which this type of formation fractures.
	4. When loss of circulation occurs and adjacent wells have not experienced lost circulation, induced fractures should be suspected.	4. Drilling may be "rough" before loss.	

of loss of circulation one of the most challenging problems of the industry. Not uncommon is abandonment of wells due to failure to regain circulation.

The magnitude of the problem prompted the initiation of an investigation of the various aspects of lost circulation. The objectives of this paper are to present the results of this investigation to date and to stimulate interest and discussion.

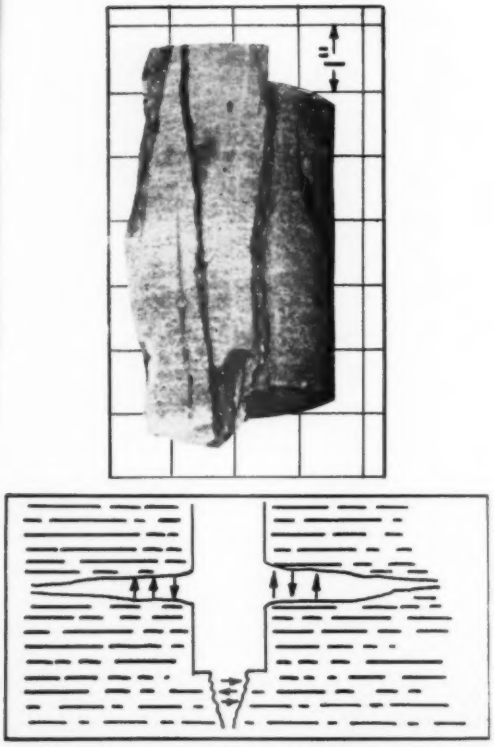

FIG. 2 — INDUCED OR CREATED FRACTURES.

FACTORS AFFECTING LOST CIRCULATION

A. TYPES OF FORMATIONS CAUSING LOST CIRCULATION

Classification

Study of literature disclosed that the types of formations or subsurface conditions which are the cause of, or are susceptible to, lost circulation have been classified numerous times by various authorities, and that there is an agreement among most authorities that the subsurface conditions fall in four categories.[1,9,18,24]

1. Natural or Intrinsic Fractures (Fig. 1).
2. Induced or Created Fractures (Fig. 2).
3. Cavernous Formations (crevices and channels) (Fig. 3).
4. Unconsolidated or Highly Permeable Formations (loose gravels) (Fig. 4).

Coring of wells has shown that induced fractures may be horizontal, vertical, or at various angles to a bore.

Induced or created fractures are distinguished from natural fractures primarily by the fact that the loss of mud to induced fractures requires the imposition of pressure of sufficient magnitude to break or split, or to part formations, while the loss of mud to natural fractures requires only sufficient pressure to exceed that of the fluid within the formation. The latter condition presupposes that in their undisturbed state some natural fractures may be wide enough to permit mud entry without compacting superimposed, underlying, or adjacent formations, and certainly the size fractures observed in many cores indicate that this is possible. In this paper, the terms natural and intrinsic fractures refer only to those fractures conforming to the conditions above. The term "fractures" used alone refers to both natural or intrinsic and induced or created fractures.

Cavernous formations differ from fractures in that caverns are probably a result of solution phenomena. Loss of mud to caverns occurs when the mud pressure exceeds the formation pressure of the caverns.

The loss of mud to loose gravel requires that the intergranular passages be of sufficient size to permit whole mud entry and, as in the case of natural fractures and caverns, the mud pressure logically must exceed the formation pressure.

Recognition

Positive identification of the type of formation causing lost circulation always is an important factor in determining a means of regaining circulation. To assist in identifying the type of formation, field observations made during and just

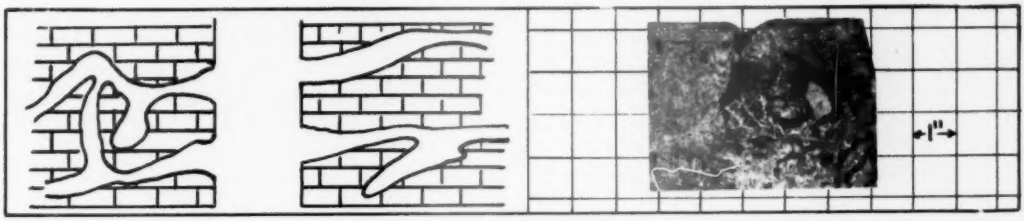

FIG. 3 — CAVERNOUS FORMATIONS.

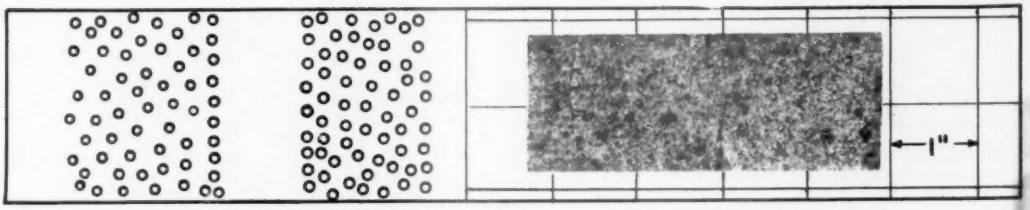

FIG. 4 — UNCONSOLIDATED OR HIGHLY PERMEABLE FORMATIONS (LOOSE GRAVELS.)

prior to the occurrence of lost circulation that are believed indicative of the type of lost circulation being encountered, together with a few other distinctive characteristics, are compiled in Table I.

Probably the most difficult type of lost circulation to control or prevent is that occurring in formations containing caverns; however, the fact that this type of lost circulation is not common in all producing areas tends to subordinate it in the opinion of the authors to the problem of controlling circulation lost to induced fractures. Such fractures are believed to be created most frequently while drilling into the abnormally high pressure formations which are encountered in a geographical belt along the coast of the Gulf of Mexico, and in sections of East and West Texas, and North Louisiana, although induced or created fracturing may possibly occur in many normal pressure areas. When penetrating these formations the use of heavy drilling muds is necessary. As a result, in many instances, the sum of the pressure of the high hydrostatic head required to control the abnormal formation pressure, plus the pressure required to circulate, may approach that pressure which will part, split, or breakdown formations and result in loss of drilling fluids. Under these circumstances, it is quite evident that any slight increase in pressure by any one of several means to be discussed later may be sufficient to destroy the close balance of pressure between formation and drilling fluid and result in the creation or widening of a fracture.

B. HOLE CONDITIONS

To define more clearly the problem of loss of mud to induced fractures, it was necessary to determine the well conditions which might contribute to or cause loss of circulation to this type fracture.

The requirements for forming fractures are pressure and surfaces upon which the pressure may act so that the resultant forces are of sufficient magnitude and are exerted in such a manner so as to tend to part or split formations.

A study of possible well bore anomalies indicates that the following conditions may exist and any one of these conditions might lead to formation fracturing and loss of mud.

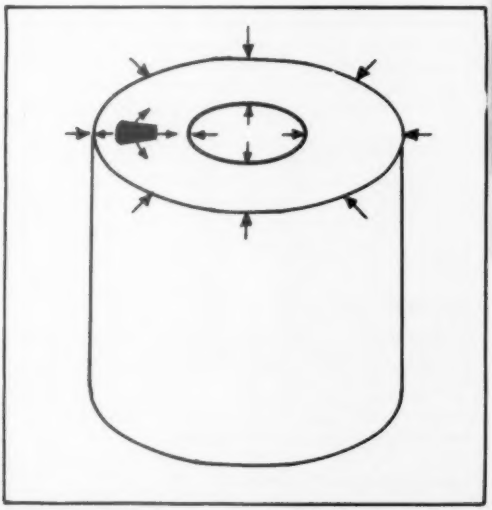

FIG. 5 — HOMOGENEOUS, IMPERMEABLE WALLS FOR FRACTURING ACCORDING TO THICK WALL CYLINDER THEORY.

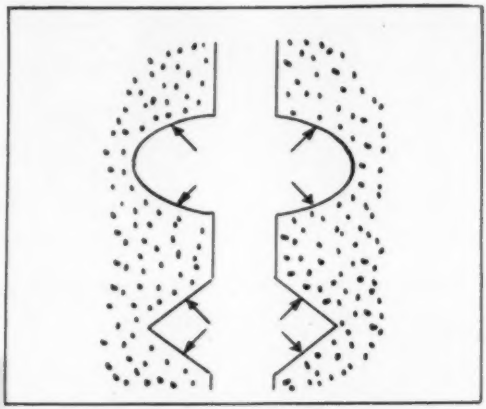

FIG. 6 — WELL IRREGULARITIES SUCH AS NOTCHES AND ELLIPTICAL ENLARGEMENTS CAUSING FRACTURING.

Homogeneous, Impermeable Walls

These conditions (Fig. 5) permit the application of the thick wall cylinder theory wherein vertical fractures occur when the internal (fluid) pressure exceeds the tensile strength of the rock, plus the unknown external pressure acting to prevent the rock from breaking in tension.

Well Irregularities

Irregularities which may cause fracturing are notches and elliptically shaped enlargements (Fig. 6).

Pressure may tend to part formations at the enlargements. At the most, the pressure must exceed the sum of the rock strength, plus the effective overburden pressure. Effective overburden pressure is defined as the pressure required to inject a fluid into a formation after it has been fractured.

Intrinsic Fractures

Drilling fluids may enter intrinsic fractures (Fig. 7), permitting pressure to act in directions perpendicular to fracture planes. The fractures widen to allow further fluid entry. The pressure need only to exceed the effective overburden pressure, plus the pressure required to extend the fractures.

Permeable Zones

Drilling fluids may enter permeable zones (Fig. 8), causing pressure to be exerted in the porous media. Formations are fractured permitting further fluid entry. At the most, pressure must exceed the sum of effective overburden pressure plus the pressure required to overcome the strength of the rock in the permeable zone along the weakest plane.

Closed Hydraulic System

With a well closed-in (Fig. 9), any surface pressure not only increases bottom hole pressure but may also place a portion of a formation in tension by exerting an upward force on the pipe equal to the surface pressure times the inside cross-sectional area of the pipe. This condition is probably significant in shallow wells only.

It is possible that any or all of these conditions may be present in a single well; thus when pressure reaches a critical magnitude, it may be expected that induced fracturing and loss of circulation will occur first in the weakest zone.

C. DRILLING FLUID PRESSURE

Pressure to Fracture

A review of the records of squeeze cementing, acidizing, and hydraulic fracturing operations in 276 wells in the Mid-Continent and Gulf Coast areas shows that bottom hole pressure gradients in wells that were intentionally fractured in the process of treatment varied 0.65 psi to 1.14 psi per ft of depth. Values as low as 0.55 to 0.60 psi per ft of depth have been reported from other sources. These pressure gradients are obtainable with muds weighing from 10.5 lb/gal to 22 lb/gal. A plot of the pressure required to fracture the formations appears in Fig. 10. The significance of the depicted data is that it may be possible to fracture formations with the hydrostatic pressure created with muds weighing less than those frequently employed in current drilling operations. After the occurrence of fracturing, the pressure required to displace fluids into formations is substantially lower than that required for fracturing. See Fig. 11.

The data in Figs. 10 and 11 emphasize the importance of maintaining the lowest possible pressure against formations to

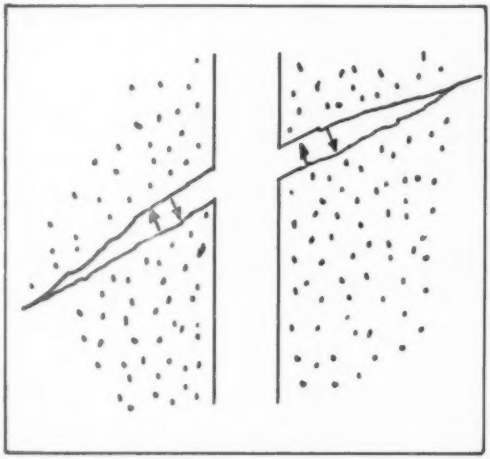

FIG. 7 — INTRINSIC FRACTURES AS THE CAUSE OF ADDITIONAL FRACTURING.

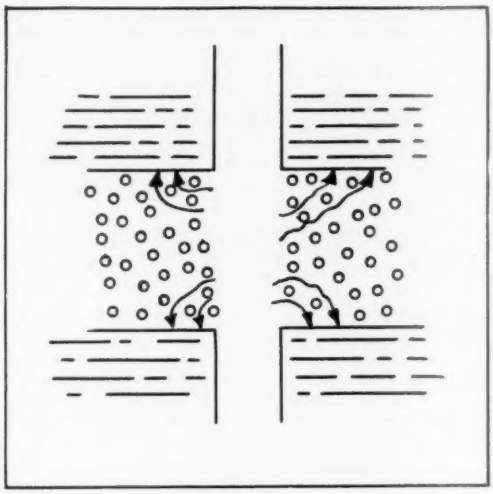

FIG. 8 — PERMEABLE ZONES AS THE CAUSE OF FRACTURING.

prevent lost circulation and are intended to serve as a guide in predicting what pressure may be regarded as in the critical zone.

Causes of Excessive Pressure

It has already been shown that the hydrostatic head of a column of mud may be sufficient to fracture a formation even before imposing the additional pressure required for circulation of the mud. With the hydrostatic pressure near a critical point and reduction of mud weight limited by the pressure necessary to control formation fluid pressure, the variables which affect the circulating pressure become an important consideration.

Changes in certain mud properties may directly or indirectly affect the circulating pressure. The most important are:

1. Drilling Mud Weight.

In addition to a reduction in hydrostatic head, it has been demonstrated by other investigators that as mud weight decreases, the pumping pressure for a constant circulating rate decreases proportionately.[6]

2. Flow Properties.

Experimentation has shown that drilling muds behave as plastic fluids[9,10,11] and, therefore, while in laminar flow, any reduction of yield value and rigidity permits an appreciable reduction in pump pressure while maintaining a constant rate of flow. The effect of varying the flow properties is shown in Fig. 12. If the yield value t_y and rigidity n, as defined by curve A are reduced to t_{y1} and n_1, as defined by curve B, it may be noted along the ordinate that the pressure drop required for a constant velocity in the region of laminar flow is much lower for curve B than curve A. In the region of turbulent flow the change in pressure from curves A to B for a constant velocity is less pronounced.

3. Filtrate Rate.

A high filtrate rate mud may indirectly increase pressure against formations by creating a thick filter cake which restricts mud flow up the annulus or may cause bridging.

Other causes for increases in pressure are:

1. Inertia of Mud Column.

When circulation is stopped for a period of time, any sudden application of pressure to start circulation may impose an unnecessarily high pressure peak on a formation due to the gel strength and inertia of the column of mud.[2]

2. High Circulating Rate.

The use of high circulating rates to remove cuttings in many instances imposes excessive pressure on formations. The same efficiency of cutting removal may be achieved without danger of causing lost circulation by altering the mud properties.

3. Hole Enlargements.

Hole enlargements may reduce mud velocity so as to allow cuttings to accumulate and then bridge at the point where the annulus is nearer normal causing pressure surges.

4. Surging of Pumps.

The results of an investigation conducted on a drilling rig in West Texas indicated that a variation in bottom hole annular pressure greater than 250 psi may be expected due to pump surges. Such a surge in a well 5,000 ft deep would be equivalent to increasing the mud weight over 1 lb/gal.

5. Swelling of Casing Protectors.

Swelling of casing protectors may cause restrictions in the annulus which necessitate increases in pump pressure to maintain a desired circulating rate.

6. Lowering of Drill Pipe.

One of the frequent causes of increased pressure is rapid lowering of the drill pipe. The bit forces fluid ahead at a greater rate than the fluid can flow back through the fluid ports. This failure of the fluid ports to accommodate the displaced mud may result in a pressure peak on the exposed formations.

PREVENTION OF LOST CIRCULATION TO FRACTURES

Precautionary measures to eliminate high pressure and pressure surges evidently many times fail to prevent the creation of fractures and loss of mud. The difference in the pres-

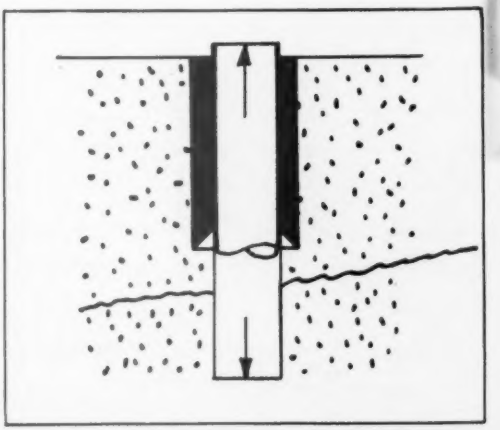

FIG. 9 — CLOSED HYDRAULIC SYSTEM CAUSING FRACTURING.

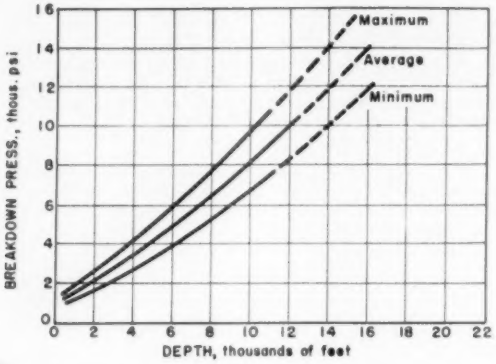

FIG. 10 — FORMATION BREAKDOWN PRESSURES OBSERVED DURING TREATMENT OF 276 WELLS IN THE MID-CONTINENT AND GULF COAST AREAS.

sure capable of fracturing formations and that required to control formation pressure is often so slight that loss of circulation is unavoidable. Study of possible means of preventing fracturing under this condition suggests that the presence of a suitable material in the mud at the instant fractures occur or are encountered should serve to plug the fractures immediately and thereby prevent the fluids from entering and widening the fractures. Such a preventative measure would achieve its effectiveness by sealing the fractures in their incipient state rather than after they have been widened and extended by inflow of mud. Practical application of this theory would now suggest the use in the mud stream of the maximum effective concentration of the most effective lost circulation material for plugging fractures.

A series of tests were initiated to determine the most effective materials for plugging fractures and to determine the maximum effective concentration of these materials.

Comparison of Materials

With a variety of lost circulation materials available, tests and organized study were facilitated by first classifying the materials with respect to their physical properties. It was found that almost all lost circulation materials fall into one of the four following classifications:

1. Fibrous — additives which have relatively little degree of rigidity and are pictured as tending to mat or entangle on the surface of or within a formation capable of taking mud.

2. Granular — additives which have rigidity and thus are able to bridge and wedge either at the face of or within formations capable of taking mud.

3. Lamellated — additives with the appearance of thin layers, scales, flakes, or sheets which may or may not have any degree of rigidity. The action of such an additive is to mat as shingles over a formation face or bridge in restrictions in a fracture.

4. Dehydratable — materials which are capable of being deprived of their carrier or extraneous fluids and thus formed into a semisolid plug through which drilling fluid particles cannot penetrate.

To compare selected materials representative of all four types, tests were made of the ability of the materials to seal simulated fractures and loose sands and gravels.

Fractures were simulated by placing cement on both sides of a metal shim, 18 in. long, centered inside of a pipe, 5½ in. in diameter, which was lined with sheet rubber, ½ in. thick. Removal of the shim after the final set of the cement created a smooth fracture 4 in. wide, 18 in. long, and with a clearance equal to the thickness of the shim (see Fig. 13). Pressure taps were placed at intervals along the pipe. The test fractures described were so designed to permit expansion or enlargement should pressure be imposed on the fracture planes. In this manner bottom hole lost circulation conditions

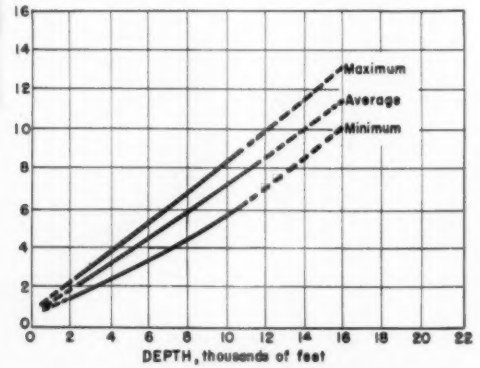

FIG. 11 — PRESSURES TO INJECT FLUIDS INTO FRACTURES AS OBSERVED DURING THE TREATMENT OF 276 WELLS IN THE MID-CONTINENT AND GULF COAST AREAS

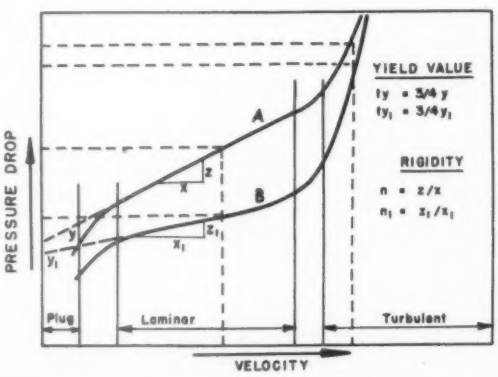

FIG. 12 — EFFECT OF CHANGING MUD FLOW PROPERTIES.

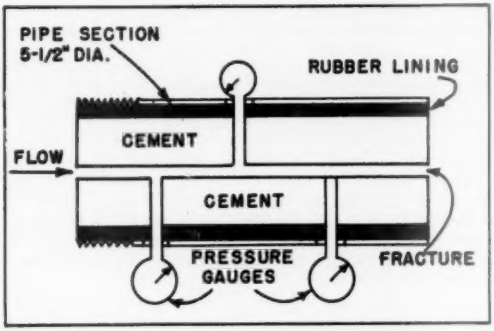

FIG. 13 — SIMULATED TEST FRACTURE.

were partially simulated. The pipe sections containing the simulated fractures with clearances of from .017 to more than 0.2 in. were hung in a vertical position from a manifold connected to a piston type pump. This range of fracture clearances was selected because it compared to that observed in cores removed from wells following loss of circulation and cement squeeze operations. The testing procedure consisted of pumping drilling mud containing controlled concentrations of lost circulation materials through the fractures until a seal was effected which would withstand 1,000 psi pressure differential. With each size fracture the concentration of material was increased in small increments until a seal was achieved or until the poor pumpability of a high concentration precluded further tests. The volume of mud which passed through a fracture before obtaining a seal was measured and recorded. If 40 gal were pumped through a fracture and failed to seal, the particular concentration was judged incapable of sealing the size fracture being tested. The results of representative tests are shown in graphical form in Fig. 14. The importance of the use of the maximum effective concentration of material is clearly demonstrated in this figure. For example, as in the case of the fibrous material, a concentration of 12 lb/bbl is indicated to be capable of sealing a fracture with a clearance of 0.11 in.; whereas a concentration of 4 lb/bbl was found capable of sealing a fracture with a clearance of only .07 in. Within the limits of pumpability any concentration in excess of 12 lb/bbl would not seal any fracture larger than .11 in.; therefore 12 lb/bbl becomes the maximum effective concentration of the particular fibrous material.

Fig. 15 presents a summary of the evaluation tests by listing the additives in the order of effectiveness which in the tests was determined by the size fracture which was sealed. This compilation indicates that the most effective materials for plugging fractures and withstanding high pressure differentials are the granular type.

Material Plugging Characteristics

In agreement with previous work with granular materials, it was found that the effectiveness of all granular materials is dependent upon a proper gradation of particle sizes to give the bridged mass of particles a sufficiently low permeability to prohibit the passage of fluids and thereby be an effective seal.

Inspection of the seal effected by fibrous, granular, and lamellated materials revealed that the seal occurred at the entrance of the fractures, thus fluid pressure was prevented from being exerted within and widening the fractures, as was evidenced by the zero readings on pressure gauges connected to the fracture while the pressure at fracture face read 1,000 psi. This manner of sealing may offer an effective solution to the problem of prevention of mud loss to fractures.

The results of tests conducted in a number of laboratory shallow wells indicate that dehydratable materials such as cement or high fluid loss mud have been successful in regaining circulation in formations previously fractured. These results were substantiated by a test in the High Island Field at a depth of 1,538 ft where a formation was intentionally fractured just below the surface casing. The use of a set-killed high-water-loss cement forced into the fracture permitted an increase in circulation pressure to a value above that originally required to breakdown the formation. This action is similar to that which is experienced when obtaining high final pressures during cement squeeze operations. The effectiveness of a dehydratable material may depend upon the presence of a permeable zone and it is improbable that shale sections could afford in the walls of all fractures the permeability necessary to allow dehydration. However, this does not preclude the possibility of the material dehydrating through its own mass within the fracture itself, once a bridge is formed in a restriction, so as to form a plug capable of preventing the flow of whole mud and loss of circulation.

All of the materials, except the dehydratable type, were tested through loose gravel and sand and found capable of effecting a seal. Due to the similar sealing characteristics of all the materials in sands and gravels, no comparison was made in this respect.

With granular materials indicated to be most suitable for preventing fracturing, additional tests were initiated to substantiate the merits of these materials. The first series of tests consisted of squeezing a low-water-loss cement containing a granular lost circulation material into a well in a simulated homogeneous formation to determine the ability of the material to prevent enlargements of fractures. An example of the

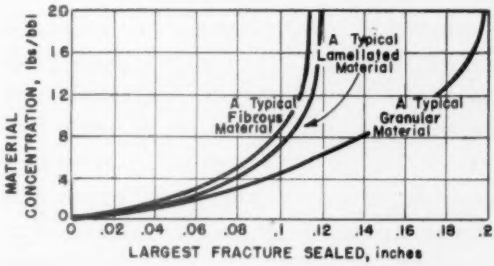

FIG. 14 — EFFECT OF CONCENTRATION OF LOST CIRCULATION MATERIALS WHEN SEALING FRACTURES.

results obtained in these tests is shown in Fig. 16, which shows a horizontal cross-section of the well after the cement slurry had set under pressure. The formation was fractured, but extension of the fractures appeared to have been prohibited by the bridging of the granular material at the initial stages of the fractures.

The second series of tests was conducted in shallow wells drilled in the laboratory yard. The ability of granular lost circulation material to prevent the occurrence of lost circulation was illustrated in a test in two ft of open hole in a well 15 ft deep. The formation was fractured at a pressure of 1,100 psi and mud containing a granular material pumped into the hole. The material sealed the fracture and permitted the imposition of 3,000 psi pressure. The well was pumped dry, and by employing a system of mirrors, the open hole section was photographed. A picture typical of those obtained appears in Fig. 17, where granular materials bridged and matted at the entrance of two fractures may be seen. This test indicated that the presence of a surface sealing lost circulation material in the mud permitted the application of pressure well above that normally required to fracture the formation and apparently prevented the fluid pressure from acting within the fracture already created.

Disposing of Cuttings and Reclaiming Lost Circulation Materials

To use lost circulation materials while penetrating zones susceptible to lost circulation would require that the materials be added to the mud stream frequently to compensate for losses on the shale shaker or that the shale shaker be removed and the accumulation of cuttings be disregarded until the concentration became high. In the latter case, the cuttings could be removed by jetting them off the bottom of the mud pits or by replacing the shale shaker. Both methods result in a loss of lost circulation materials. To reduce this loss, several measures were considered, including the use of ore shaking table which utilizes the difference in particle density and size and the use of a centrifugal sorter.

The use of a new type centrifugal sorter was favored over the other means because of its ability to handle many different lost circulation materials regardless of their physical properties.

The centrifugal sorter, a cross-section of which is shown in Fig. 18, operates by a power impeller forcing the mud containing cuttings and lost circulation materials into a rotating, perforated, separating impeller within a shell or chamber. As the mud enters the individual perforations of the separating

MATERIAL	TYPE	DESCRIPTION	CONCENTRATION LBS/BBL
NUT SHELL	GRANULAR	50%-3/16+10 MESH 50%-10+100 MESH	20
PLASTIC	"	"	20
LIMESTONE	"	"	40
SULPHUR	"	"	120
NUT SHELL	"	50%-10+16 MESH 50%-30+100 MESH	20
EXPANDED PERLITE	"	50%-3/16+10 MESH 50%-10+100 MESH	60
CELLOPHANE	LAMELLATED	3/4 inch FLAKES	8
SAWDUST	FIBROUS	1/4 inch PARTICLES	10
PRAIRIE HAY	"	1/2 inch FIBERS	10
BARK	"	3/8 inch FIBERS	10
COTTON SEED HULLS	GRANULAR	FINE	10
PRAIRIE HAY	FIBROUS	3/8 inch PARTICLES	12
CELLOPHANE	LAMELLATED	1/2 inch FLAKES	8
SHREDDED WOOD	FIBROUS	1/4 inch FIBERS	8
SAWDUST	"	1/16 inch PARTICLES	20

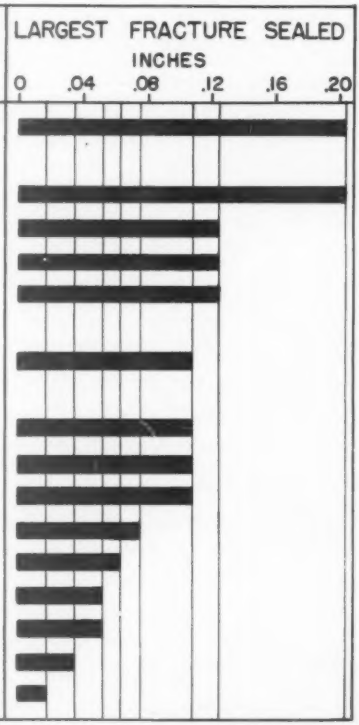

FIG. 15 — SUMMARY OF MATERIAL EVALUATION TESTS.

impeller, centrifugal force tends to throw the high density cuttings back into the chamber, while part of the low density materials are allowed to pass through with the mud. Cuttings are carried out the reject line while an almost unchanged concentration of lost circulation material is carried out the discharge line.

For testing purposes, the sorter was assembled with both reject and discharge lines emptying into the suction tub.

The lost circulation materials tested consisted of ground nut shells, 1/8 in. sawdust, ground plastic, 3/8 in. and 3/4 in. cellophane flakes, and 1/2 in. prairie hay. Mud properties, sorter RPM, and discharge rates were varied and the efficiency of separation observed. To determine additive and cutting concentrations, samples were taken at the discharge and reject outlets. The samples of cuttings and materials were screened, washed, separated in a mixture of bromoform and alcohol, dried, and weighed. Results of tests are shown in Table II.

Analysis of the compiled data shows that the suction concentration of 100-mesh and larger cuttings was reduced from 100 lb/bbl to less than 2 lb/bbl, while a nearly constant concentration of lost circulation material was maintained from suction to discharge. It was noted during tests that the weight of mud containing barite was not altered when passing through the sorter and mud filtrate rate and viscosity were not affected.

The use of the sorter in the field to serve as a means for concentrating cuttings to be rejected and for reclaiming lost circulation materials might introduce technical difficulties which were not apparent in the laboratory. The effectiveness under actual operating conditions remains to be determined by field tests.

CONCLUSIONS

From the test data compiled to date and from the results of the study of the factors believed by the authors to affect lost circulation, it may be concluded that by incorporating the maximum effective concentration of a proper gradation of granular material in a mud stream when zones susceptible to lost circulation are penetrated, it should be possible in many instances to reduce to a minimum the loss of circulation to fractures by the effective plugging action of granular materials at the moment such fractures are created or encountered. More specifically, the study has shown as follows:

1. Induced fractures may be a frequent cause of lost circulation.
2. The pressure normally employed while drilling may in many instances be sufficient to cause fracturing of rock formations.
3. Granular lost circulation materials in a proper gradation of particle sizes were found by laboratory tests to be the most effective type material for controlling mud loss to fractures.
4. Limited test data indicate that dehydratable materials are effective for regaining circulation.
5. Tests in shallow and simulated wells indicate that the maximum effective concentration of a proper gradation of

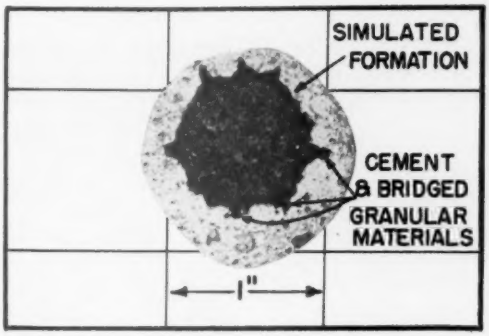

FIG. 16 — EFFECT OF GRANULAR MATERIALS IN CEMENT.

Table II — Results of Tests with Centrifugal Sorter Used for Separating Bit Cuttings and Lost Circulation Materials

Test No.	Conc. lbs./bbl.	Type	SUCTION PIT ANALYSIS: Mud Properties: Wt. lbs./gal.	Vis sec.	Fluid Loss cc/7½ Min.	Cuttings Conc. lbs./bbl. (Approximate)	REJECTED MUD ANALYSIS: Lost Circ. Material Concentration lbs./bbl.	Cuttings: Concentration in lb./bbl. Retained on U. S. Standard Sieve: No. 40	No. 100	No. 200	Mud: Vol. gpm	Wt. lbs./gal.	Vis sec.	Fluid Loss cc/7½ Min.	DISCHARGE MUD ANALYSIS: Lost Circ. Material Concentration lbs./bbl.	Cuttings: Concentration in lb./bbl. Retained on U. S. Standard Sieve: No. 40	No. 100	No. 200	Mud: Vol. gpm	Wt. lbs./gal.	Vis sec.	Fluid Loss cc/7½ Min.	RPM
1	23	Walnut Shell Grnd -10+16 Mesh	9.5	48	14	None	25.8	—	—	—	200	—	—	—	20.6	—	—	—	300	9.5	48	14	1000
2	20	Walnut Shell Grnd -3/16"+10 Mesh	9.6	48	14	None	24.6	—	—	—	200	—	—	—	21.0	—	—	—	300	9.6	48	14	1000
3	18	Walnut Shell Grnd -10+16 Mesh	11.4	60	12	10	17.0	12.2	1.1	3.1	300	11.4	—	—	19.0	0.2	0.6	3.1	300	11.4	60	12	1000
4	9	Pine Sawdust 1/8"	9.5	57	—	10	8.9	—	15.5	3.3	300	—	—	—	8.8	—	0.3	2.2	300	9.5	57	—	1250
5	8	Pine Sawdust 1/8"	9.5	135	—	10	8.9	—	12.8	3.5	300	—	—	—	8.7	—	0.6	2.6	300	9.5	130	—	1200
6	12	Ground Plastic -10+200 Mesh	9.5	60	—	10	11.9	14.7	1.4	2.2	300	—	—	—	10.2	0.8	0.4	2.2	300	9.5	58	—	1100
7	20	Prairie Hay 1/2"	9.5	35	—	5	25.0	—	6.8	1.0	300	—	—	—	15.0	—	(Trace)	1.0	300	9.5	36	—	1100
8	8	Cellophane 3/8"	9.5	45	—	5	9.3	6.2	0.2	1.1	300	—	—	—	6.3	(Trace)	(Trace)	1.0	300	9.5	45	—	1100
9	8	Cellophane 3/8"	9.5	50	—	2	11.0	—	20.0	—	14	—	—	—	7.8	—	1.0	—	500+	9.5	50	—	1200
10	10	Walnut Shell Grnd -10+16 Mesh	9.5	30	—	2	9.7	4.2	1.0	—	60	—	—	—	8.5	0.6	0.8	—	425+	9.5	30	—	1100
11	6	Walnut Shell Grnd -10+16 Mesh	9.5	56	—	70	6.0 Nuts	119.0	—	—	200	—	—	—	6.0 Nuts	19	—	—	300	9.5	56	—	1000
	4	Pine Sawdust					4.8 Saw								3.3 Saw								
12	5	Walnut Shell Grnd -10+16 Mesh	9.5	56	—	75	5.9 Nuts	140.0	2.2	—	200	—	—	—	3.7 Nuts	0.4	1.5	—	300	9.5	56	—	1400
	3	Pine Sawdust 1/8"					3.0 Saw								3.0 Saw								
13	10	Walnut Shell Grnd -10+16 Mesh	9.5	56	—		11.0 Nuts	184.0	4.0	—	300	—	—	—	9.0 Nuts	1.0	1.8	—	300	9.5	54	—	1400
	8	Pine Sawdust 1/8"				100	8.4 Saw								7.5 Saw								
	8	Cellophane 3/4"					8.5 Cello								7.3 Cello								

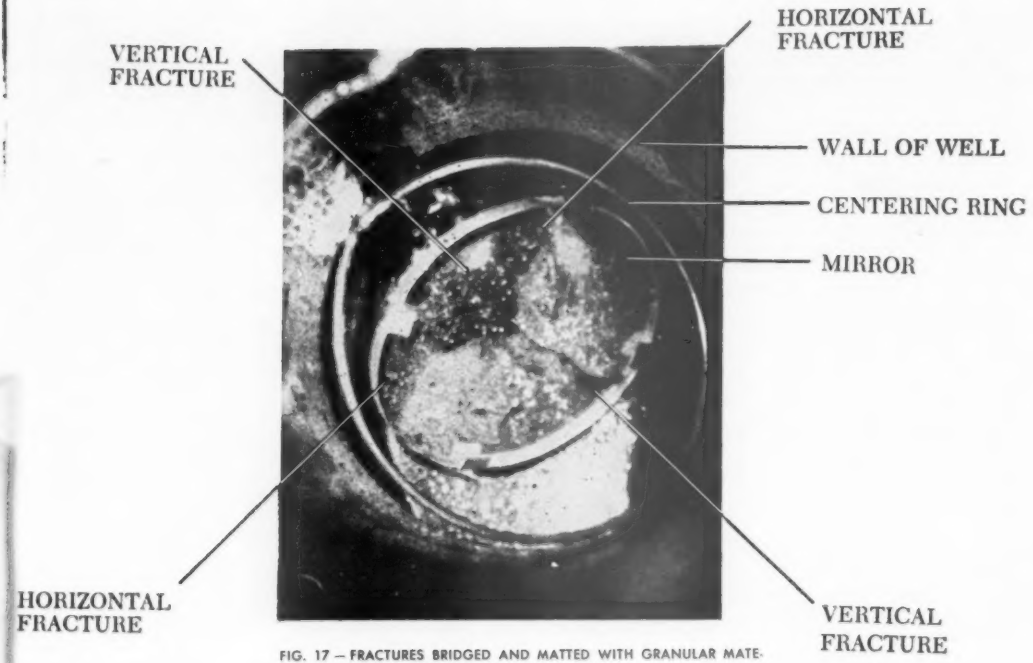

FIG. 17 — FRACTURES BRIDGED AND MATTED WITH GRANULAR MATERIAL AS PHOTOGRAPHED IN SHALLOW TEST WELL.

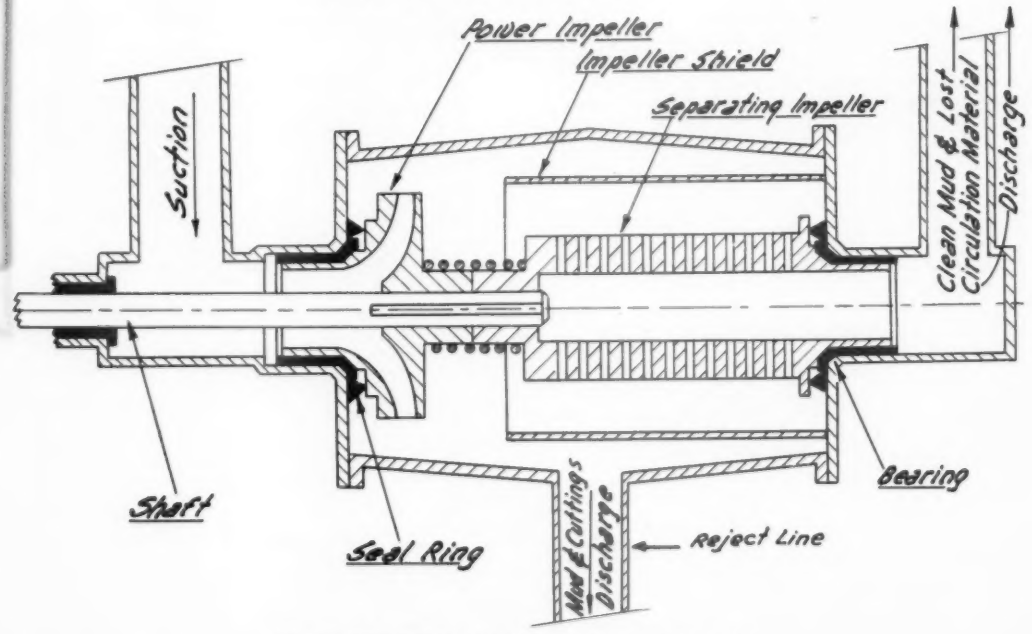

FIG. 18 — CROSS SECTION OF CENTRIFUGAL SORTER FOR USE IN SEPARATING CUTTINGS AND LOST CIRCULATION MATERIALS.

granular material in drilling fluids permits the imposition of higher pressure than normally is required to fracture formations.

6. In laboratory tests a new type centrifugal sorter was found suitable for concentrating cuttings to be rejected and reclaiming lost circulation materials.
7. The concentration in mud of a lost circulation material is a critical factor affecting the ability of the material to seal fractures.

The problem of lost circulation is of sufficient importance to justify considerable work in the future. While it is the hope of the authors that the methods of prevention and control of lost circulation advanced in this paper will aid materially in the solution of the problem, it is fully recognized that additional effort must be directed towards a more positive method.

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★ ★ ★

DISCUSSION

By George E. Cannon, Member AIME, Humble Oil and Refining Co., Houston, Tex.

Howard and Scott have done an excellent job in the evaluation of lost returns materials and their analysis of the problem is both concise and complete; however, there are two statements in the analysis which we believe should be clarified. These statements are in the Drilling Fluid Pressure section under Causes of Excessive Pressure, and are as follows:

1. Drilling Mud Weight. The statement that drilling mud weight has an effect on mud pressure is true; however, the majority of pressure increase or decrease due to increased or lowered mud weight occurs inside the drill pipe. Because of this, circulating pressure in the annular space is not appreciably affected by mud weight as implied by the statement; therefore, mud weight would have a greater tendency to cause fractures through exerting a hydrostatic head than through increased frictional resistances.

2. Flow Properties. This statement is also true in that flow properties of a drilling fluid affect the pressure required to move the fluid at a constant velocity in laminar flow; however, cases are rare in which flow of fluid in the annulus is laminar. Such a small velocity is required to achieve turbulent flow in the annular space that laminar flow seldom exists.

DISCUSSION

By Preston E. Chaney, Sun Oil Co., Beaumont, Tex.

In evaluating fibrous or granular materials for controlling lost circulation, it is essential that we understand the mechanism responsible for lost circulation. In those cases where circulation is lost to gravel beds, cavernous or highly fractured

formations, the use of granular materials is quite logical and has a reasonable chance of success.

However, in the case of abnormal pressure wells, in which the hydrostatic pressure of the mud column approximates the overburden pressure the use of such materials is not so clearly indicated. By methods such as spinner surveys, and temperature surveys using chilled or heated muds it has been established that circulation is lost to non-porous shale beds at least as often as to sands under abnormal pressure conditions.

In such cases, circulation is lost by tensile failure of the formation produced by internal pressure in excess of the compressive load of the overburden. Since this involves the same factors as the failure of a pressure vessel, the laws governing the design of thick walled pressure vessels should apply. Elastic theory teaches that a pressure vessel, even though the wall thickness be infinite as compared to the diameter of the bore, cannot withstand an internal pressure in excess of the ultimate tensile strength of the material from which it is constructed. This conclusion is certainly not obvious, but may be visualized as follows: Internal pressure is first applied to the fibers nearest the bore of the pressure vessel. This load can be shared by more distant fibers only by elongation of these internal fibers. The diameter, and therefore, the circumference of the bore must increase in order to permit transfer of the load to these more distant fibers. If the internal pressure be in excess of the ultimate strength of the material, the internal fibers are stressed to failure before the most distant fibers accept any appreciable portion of the stress.

Our problem thus resolves to the question of the best method of operating a pressure vessel stressed to its ultimate strength. It is not sufficient to plaster the cracks produced by failure of the walls of the bore hole because this merely transfers the problem to fibers more distant from the well bore, but no more capable of withstanding the load than those which failed originally.

We must either increase the tensile strength of the walls of the bore hole, or decrease the pressure applied to the formation. At present we have no means for appreciably increasing the tensile strength of the formation. Therefore we must concentrate on reducing the applied pressure to the minimum consistent with safe drilling practice. The minimum mud weight is dictated by the requirement that the hydrostatic pressure of the mud column be slightly in excess of the formation fluid pressures encountered. This is the absolute minimum pressure that must be applied to the walls of the bore hole.

However, in addition to this pressure, there are numerous surge or peak pressures resulting from balling of the bit or drill collars, rapid lowering of the drill pipe, or sudden starting of the pumps when starting circulation. The magnitude of these surge pressures is demonstrated by Goins,[1] and is quite large in terms of equivalent mud weight increase. These surge pressures are at least partially within our control and we should make every effort to eliminate them.

An additional pressure loading on the well bore is the pressure differential in the annulus required to circulate the mud. This pressure is dependent upon the rate of circulation and the viscosity of the mud, both of which are subject to control within limits. It seems desirable to reduce circulation rate to the minimum consistent with cutting removal, even though this requires a considerable reduction in drilling rate. Also, it seems essential to maintain the mud viscosity at a minimum. It is in this connection that I question the advisability of adding granular materials to prevent or combat lost circulation under abnormal pressure conditions. If such materials be added to a concentration sufficient to reduce the pumpability of the mud, it seems they might aggravate rather than correct the trouble.

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AUTHORS' REPLY TO MR. CHANEY

Chaney's criticism is well founded — *if* the thick wall cylinder theory applies directly to porous rock formations, failure would be expected at or in the range of the tensile strength of the surrounding rock. The formation breakdown pressure would, therefore, be equal to rock strength (approximately the tensile strength if the thick wall cylinder theory applies), plus the confining effect of the overburden. Applying this rule to the 15 ft shallow well test, cited as an example in the reference paper, the formation breakdown would be expected to occur at approximately 540 psi, or 525 psi (tensile strength) plus 15 psi (overburden). In this shallow test the initial breakdown with mud occurred at 1,100 psi. The difference in the 540 psi calculated and the 1,100 psi actually observed in this test is partly accountable to surges in pressure during breakdown operations and is partly believed to be due to variations in tensile strength of the sandstone, as compared to the tensile strength of a tested sample. The 3,000 psi pressure imposed and held for better than 30 minutes in this previously fractured shallow well, after the introduction of granular lost circulation recovery material, indicated that pressures greatly in excess of the tensile strength of the surrounding rock, plus the overburden pressure, can be imposed by incorporating a proper gradation in size of a granular material in the drilling mud. ★ ★ ★

A GRAVEL PACK COMPLETION FOR EXCLUSION OF GAS AND WATER

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ABSTRACT

A gravel pack completion is described which, in addition to sand screening, permits the exclusion of water and gas from the oil production.

A gravel pack composed of alternate layers of different particle sizes is employed which has horizontal but not overall vertical permeability to drilling mud. A packer is run on the tubing and set in the screen member, around which the gravel layers are placed. The hydrostatic pressure of a mud column prevents the entry of fluid above (or below) the level of the packer. The producing level may be changed by raising or lowering the tubing.

Vertical coning is controlled by replacing the mud column with oil and continually injecting oil into the sand section above (or below) the packer.

Three well histories with this completion are described in detail. Statistics on the first 100 completions of this general type are given.

INTRODUCTION

Gravel pack type completions have heretofore been almost exclusively for the purpose of preventing sand production. This paper describes and presents well data on a gravel pack procedure which is primarily a selective completion method. Although complete sand screening is achieved, the exclusion of gas and water is the primary objective. The application of this procedure is therefore not limited to unconsolidated sands. Application to hard sand or limestone reservoirs is equally feasible.

GRAVEL PACK PROCEDURE

Figs. 1 and 2 illustrate the gravel pack procedure employed. The gravel is placed by means of the frangible disc type dump bailer shown by Fig. 1.[1] This bailer has its lower end closed by a plate glass or steel rimmed cement disc. This disc breaks when the bailer passes over the liner allowing the gravel to be deposited around the liner. The liner employed is usually $2^3/_8$ in. to $2^7/_8$ in. OD and 1.995 in. or 2.07 in. ID (ID of 2-in. tubing or 2-in. line pipe). Two types of slotted sections have been employed. One type employs horizontal hacksaw cut or milled slots of about 1/32 in. width opposite the producing section. The other type employs the same type of horizontal slot, but slots are placed in groups of six at intervals of about 8 in. A cage composed of half round vertical bars, spaced apart, is then welded to the pipe over the slotted sections. This liner has the bottom end closed, usually by bull plugging. The upper end is closed, while placing the gravel, by a cap which is held in place by means of a shear pin. This cap has a mandrel attached to it which extends downward inside of the liner to within a few inches of its lower end. The top of the liner cap is formed to fit a releasing type wire line core barrel overshot. The liner is lowered to bottom on the wire line by means of this overshot and released. The length of the liner is usually sufficient to extend to about 20 ft above the highest level to which gravel is to be placed, the upper end of the liner always being in the casing. The dimensions of the liner and bailer are such with respect to the casing size that the bailer will always pass over the liner. After releasing the liner the bailer is run to bottom. Passage of the empty

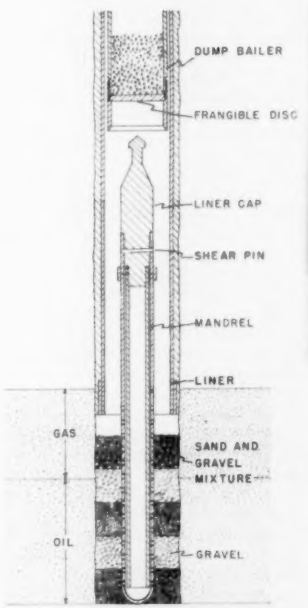

FIG. 1 — GRAVEL PACK PROCEDURE EMPLOYED.

[1]References given at end of paper.

Manuscript received in the office of the Petroleum Branch, Sept. 3, 1950. Paper presented at the Fall Meeting of the Branch in New Orleans, La., Oct. 4-6, 1950.

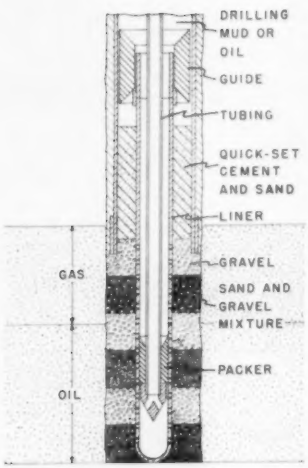

FIG. 2 — GRAVEL PACK PROCEDURE EMPLOYED.

bailer over the liner in this way serves to centralize the liner, this being the only procedure for this purpose which has proved necessary in practice.

Two types of layers are then dumped around the liner. One layer is composed of gravel of the grain size required to screen the sand. This size is determined from screen analysis of the producing sand; the gravel grain size being not larger than six times the sand grain size at the 10 per cent point on a sieve analysis curve of the sand using U. S. standard sieve series. This, of course, refers to the coarsest 10 per cent of the sand. The resulting grain size is usually about 1/16 in. The other layer is composed of this gravel with sufficient sand mixed with it to fill the gravel pore spaces. In order to prevent the sand and gravel from separating while this mixture is being dumped it is also necessary to use a binder. A binder is available for this purpose which will not only hold the sand and gravel together while being deposited but which will later flow out under about 50 psi pressure differential leaving an intimately mixed permeable sand and gravel layer. A layer is thus provided which will not flow through liner slots required for the gravel size necessary to screen the sand but which has pore space size approximating that of the producing sand. For example, drilling mud will not flow through these layers. Also exceedingly fine-grained sand may be successfully screened. The thickness of these layers is usually from 6 in. to 12 in. The thickness of the layer deposited can be determined to within about 2 in. by observing "pick up" of the dump bailer.

Alternate horizontal layers of the above two types are placed around the liner opposite the producing section and usually to about four or five ft above the bottom of the casing and at least this distance above the highest liner slot. A mixture of quick-set cement and sand is then dumped around the liner and directly on top of the gravel. The volume of cement is such that the upper four or five feet of the liner, including the cap, is above the cement. Cement is dumped with the same bailer employed for dumping gravel. After the cement has set (usually about two hours after dumping) the cement fill up is checked by running the dump bailer empty. If cementing is satisfactory the liner cap is engaged by means of the wire line overshot employed in running it. The shear pin holding the cap to the liner is sheared by an upward pull on the wire line and the cap and attached mandrel retrieved. The design of the liner cap is such as to permit recovery with a conventional 2 in. overshot should the core barrel type fail.

An inwardly beveled guide is run next by means of the wire line to facilitate the entry of a packer into the liner. This guide is run on a special tool which releases only when the guide passes over the liner. The guide rests on a collar provided for this purpose near the top of the liner. The length of the guide is such as to permit its positive recovery by means of a wire line type spear.

A cup type packer assembly is then run on flush joint heavy walled $1^{3}/_{4}$-in. OD tubing attached to the lower end of the tubing string. The heavy walled tubing section is usually of about the same length as the liner. Fig. 8 shows the type of packer assembly employed for shutting off the upper portion of the sand section such as required for excluding gas. For obtaining a shut-off both above and below the producing section, two groups of packers are mounted on a mandrel having two vertical fluid passages formed by a vertical partition. One of these passages is a by-pass extending from above the upper to below the lower packer. This passage permits the entry of mud or oil into the gravel layers below the lower pack section from the annular space between the casing and tubing. The other vertical passage permits fluid flow from the space between the packer sections to the tubing. Two methods of obtaining a shut-off of a desired portion of the producing section may be employed with these types of completion.

Water or Gas Shut-Off by Mud Column Pressure

One of the above methods is that of employing the hydrostatic head of a fluid which will not flow into the producing sand or through the mixed sand and gravel layers, but which will flow into the gravel layers. For example, if a gas shut-off is desired for the conditions shown by Fig. 2 the annular space between the casing and tubing may be filled with drilling mud. This mud will flow into the gravel layers at all levels above the packer assembly but will not flow into the producing sand or through the mixed sand and gravel layers because of the formation of an impermeable filter cake. If the hydrostatic head of the mud column exceeds the bottom hole pressure in the gas sand the entry of the gas into the well space is positively prevented. Fluid production enters the tubing below the packer through both the gravel and mixed sand and gravel layers since the latter are also permeable. A completion results which not only provides a positive shut-off in the hole space but which also permits the changing of the producing level by simply raising or lowering the tubing. The optimum producing level may thus be found after completion rendering unnecessary accurate information as to the location of the gas-oil or oil-water contacts or a preliminary guess as to what extent coning may occur. Furthermore, dependence is not made upon these contacts remaining at the same level. Precise depth measurements are also not necessary although always desirable.

By using the double packer assembly a shut-off is obtained both above and below the zone being produced. As previously described, a by-pass is provided into this case which allows mud from the casing-tubing annulus to invade the gravel layers below the packer assembly as well as above it.

Water or Gas Shut-Off By Oil Injection

The second method for obtaining a shut-off with the alternate layer type completion is that of supplying a fluid to the casing and tubing annulus which will flow into the section of the pro-

ducing sand in which a shut-off is desired. For example, for the conditions shown by Fig. 2, oil may be continually pumped down between the casing and tubing. If the face of the gas sand and adjacent gravel pack has been cleaned by back-flowing, oil flow into the gas sand results. An oil-saturated zone in the gas section is thus created adjacent to the well and in the area in which vertical coning principally occurs. Any tendency to cone results in a downward flow of oil from the previously gas-saturated section. By continually supplying oil to the casing-tubing annulus vertical coning results in the production of this oil rather than gas. As the packer assembly is raised higher a greater percentage of the oil produced is from the casing and tubing annulus, but even if the packer is above the gas-oil contact, gas will not be produced. This type of completion provides both a positive shut-off in the hole space and also a method for controlling vertical coning.

The oil injection type of completion is also applicable to preventing the upward coning of water. However, since the viscosity contrast between oil and water is less than that between oil and gas, the number of cubic feet of circulating oil per cubic foot of water coning is greater than for an equal volume of gas coning. Also the fact that gas is compressible still further reduces the volume of gas coning as measured on the surface under standard conditions in proportion to that required for the same volume of oil coning. This latter fact also indicates the use of this method for control of coning to be more favorable for application to deep wells than shallow ones. At least the volume of oil which must be supplied to the casing-tubing annulus to control a given volume of gas coning decreases with depth.

Optimum Gravel Size

One question which arises when considering the use of relatively fine gravels or sand and gravel mixtures is whether the fluid productivity is substantially reduced. Fig. 3 shows data which was published by Hill.[2] This curve shows the experimentally determined relation between permeability of the gravel pack and the ratio of the gravel size to the sand grain size at the 10 per cent point on a sieve analysis curve. The gravel permeability values were obtained in a test cell after fluid flow through sand into the gravel until apparently stable conditions as to sand invasion resulted. The permeability of the sand invaded gravel pack was then measured. It will be noted that maximum permeability of the sand invaded gravel pack occurs when the grain size of the gravel is about six times the grain size of the sand at the 10 per cent point on the sieve analysis curve. Tests which we have conducted indicated this also to be the largest gravel/sand grain size ratio for which no sand production can be induced regardless of rate of fluid flow. The grain size ratio for no sand production would obviously also correspond rather closely to the grain size ratio for which no sand invasion occurs. Any sand particle capable of entering the gravel pack should ultimately be produced with a sufficient rate of fluid flow since the passage between the gravel grains are about the same throughout. Thus for gravel/sand grain size ratio greater than six, sand invasion occurs. The pore spaces of the gravel are filled with sand, reducing the permeability. For gravel/sand grain size ratio less than six no sand invasion occurs, the permeability decreasing simply because the smaller gravel grains result in smaller pore spaces.

Our results also indicate that grain size ratio greater than six represents an unstable condition. In this range sand production is related to the rate of fluid production. Sudden increases in rate of fluid production may result in sand production. This may produce a cavity behind the gravel pack into which shale or shaly sand may cave ultimately resulting in the plugging of the gravel pack. This sequence of events has been frequently observed when relatively large gravel such as pea gravel is employed.

The dotted or upper curve in Fig. 3 shows the ratio of fluid productivity with the gravel in place to that of the open hole. This curve has been calculated for corresponding permeability values shown by the lower curve for a gravel pack filling the annular space between a $2^{3}/_{8}$-in. OD liner and a 6-in. open hole. Calculation of fluid productivity was made by use of Muskat's formula for calculating the influence of discontinuous radial variations in permeability.[3] It will be noted that maximum reduction of fluid productivity because of the gravel pack is only about three per cent for the experimentally determined values for permeability of sand invaded gravel. Also that fluid production is reduced only 15 per cent if the space between the liner and open hole is filled with sand or a sand and gravel mixture having the same permeability as the producing sand. The relations between permeability and gravel/sand grain size ratio shown by Fig. 3 are strictly true only for the sand

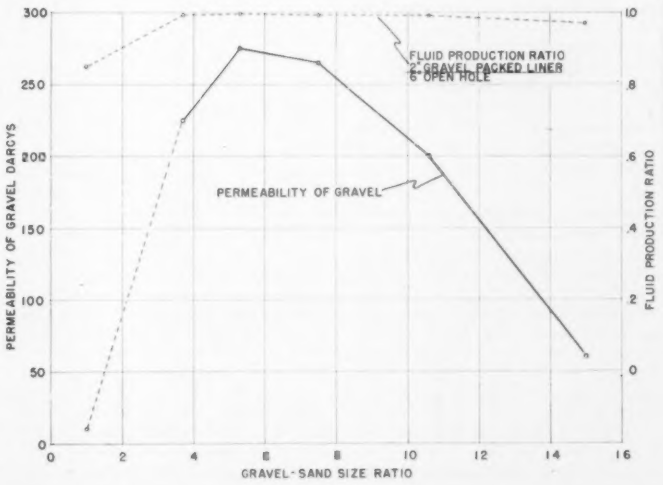

FIG. 3 — RELATION BETWEEN PERMEABILITY OF PACK AND RATIO OF GRAIN SIZE TO SAND.

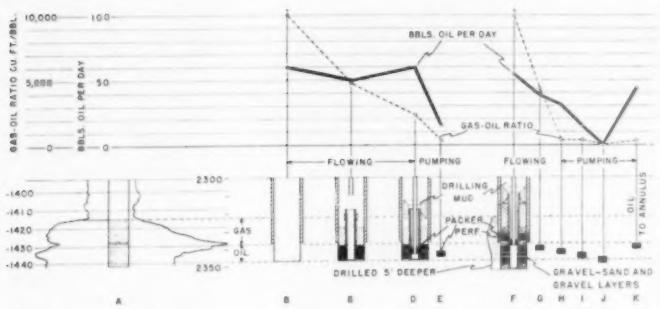

FIG. 4 — RESULTS OF ALTERNATE LAYER TYPE COMPLETION TO WELL IN QUIEN SABE FIELD, WEBB COUNTY, TEXAS.

sample employed in Hill's experiment. However, these values approximate values obtained with usual oil producing sands.

Clean-Out Procedure Prior to Gravel Packing

The use of gravel having gravel/sand ratio less than six has usually been impractical in the past because of the difficulty of maintaining a clean sand face while placing the gravel. If drilling mud is or has been present opposite the sand section, the resulting filter cake will not flow through the finer gravels or gravel-sand mixtures. If no filter cake is present and the hole filled with water, oil or similar liquid, any flow of liquid into the sand will usually result in the formation of a thick filter cake of relatively large particle size material due to the filtering out of sediment or scale on the face of the sand. Such filter cake may have a greater tendency to plug the gravel than would drilling mud.

Attempts to apply fine gravels to old unconsolidated sand wells have usually resulted in plugging of the gravel pack with commonly used procedures for cleaning out before gravel packing. Such wells frequently have large cavities in the sand section. These cavities are usually filled, or partially filled, with sand and/or shale cavings. Such cavities ordinarily cannot be completely cleaned out with a bailer or sand pump or by fluid circulation although it may be possible to reach the original bottom of the hole. This condition usually results in a layer of sand and shale or silt between the gravel and the sand face resulting in initial plugging or reduced fluid production.

Fluid flow from the sand has been most commonly employed for cleaning the sand face prior to gravel packing in low pressure sands. After drilling out the casing shoe and open hole section the tubing is run and swabbed until fluid flow from the sand results. If gas flow develops, gas is bled through a small choke until the well heads up with fluid and dies. The tubing is then pulled and sand or cavings in the open hole section cleaned out with a sand pump or bailer. This procedure requires the sand to be consolidated to such an extent that caving does not occur with the pressure due to the fluid column in the hole equal to the bottom hole pressure of the sand.

Soluble Mud

For cases in which the walls will not stand up as required above, a mud has been developed which forms a water soluble filter cake. A dump bailer is employed for spotting about 100 ft of this mud on bottom. By spudding the bailer with the fluid column in the hole equal to the bottom hole pressure of the sand, any fine material on the sand face is forced off by momentary fluid flow due to swabbing action of the bailer and held in suspension in the mud column. Fluid flow into the hole while soluble mud is being dumped may also be induced by bailing from the top of the fluid column. Such fluid flow may be employed for moving cavings into the hole resulting in their suspension in the soluble mud. By alternately bailing out the resulting mud and sand mixture and dumping clean mud, cavings may be effectively cleaned out of large cavities. A special bailer has been developed which accomplishes these two results simultaneously, mud being discharged at bottom at the same time an equal amount of fluid is pulled into the bailer about 100 ft above bottom. When clean mud returns are secured from the latter level the hole may be loaded with oil or water to support the walls against caving during the gravel pack operation. A hydrostatic head due to fluid column in the hole exceeding that in the sand results in the formation of a relatively thin (1/16 in. or less) filter cake on the sand face which may be dissolved after gravel packing by washing with water or which will be ultimately dissolved by connate water from the adjacent formations even if washing is not employed.

Several high pressure wells have been gravel packed by filling the hole with saturated brine. Such brine solutions may be prepared which have weights as high as 10 lb per gal.

Another method employed on high pressure wells has been that of spotting 200 ft to 300 ft of soluble mud on bottom back of tubing having a production packer on its lower end. This packer is then set and tubing swabbed. When sufficient flow has occurred to clean the sand face the packer is released. This results in a flow of soluble mud past the sand face and into the tubing. Any sand or cavings present are carried into the tubing and at the same time a soluble filter cake is formed on the sand face. By providing a valve on the bottom of the tubing which closes when it is picked up, most of the sand and cavings resulting from swabbing are brought out in the tubing.

TYPICAL FIELD RESULTS

Case 1

Fig. 4 shows the results of an alternate layer type completion to a well in the Quien Sabe Field in Webb County, Tex. Production is from the Lopez sand of the Mirando series at a depth of about 2,300 ft. The depths shown are subsea values. About 15 ft to 18 ft of gas saturation is present in the upper portion of the sand section with about 6 ft to 9 ft of oil saturation in the lower part of the sand. The sand is clean, uniform and medium grained but contained one hard non-permeable sand streak, the casing having been set on

this. This point was believed, on the basis of drill stem test data on the offset well, to be five ft below the gas-oil contact. Subsequent development indicates that casing was set approximately at the gas-oil contact.

When swabbed in prior to gravel packing this well made a large volume gas with a spray of oil.

The completion shown by Fig. 4-C was then tried. The lower portion of the sand section was packed with alternate layers to within about three ft of the bottom of the casing. A non-permeable mixture of gravel, sand, silt, aquagel and grease was placed in this space. The liner was then cemented in the usual manner. A 24-hour production test yielded 48 B/D flowing through ¼-in. choke with gas/oil ratio of 4,700 cu ft per bbl.

A packer of the type previously shown was next run to the indicated level, Fig. 4-D. The results of tests with the packer set at various levels are shown. With the bottom of the packer six ft below the bottom of the casing (Fig. 4-D), production was 58 B/D flowing with a gas/oil ratio of about 2,300 cu ft per bbl. With the bottom of the packer eight ft below the bottom of the casing (Fig. 4-E), production was 15 B/D pumping with gas/oil ratio of 250 cu ft per bbl.

Since it was believed that the entire sand section had not been penetrated, the gravel pack was removed and the well drilled five ft deeper with a spudder. The bottom five ft of the casing was then perforated to provide a greater zone for oil injection into the gas sand. This section was again gravel packed using alternate layers of sand and gravel about one ft thick, these layers also covering the perforated section. Production tests were then run with the packer at various levels with the annular space between the casing and tubing filled with drilling mud. Results of these tests are shown graphically (Fig. 4-F to 4-J). The production varied from a spray of oil with a large volume of gas for a packer position above the gas-oil contact to a complete gas shut-off with oil production by pumping for the two lower packer positions. No fluid production resulted when the packer was positioned below the permeable section of the sand. Also of interest is the similarity of fluid production for a given level of the packer to that obtained for the same packer level on the previous alternate layer completion.

The mud column was then circulated out with water and after thorough washing this was followed by oil which had been filtered through a sand filter. The packer was set 4 ft below the casing (Fig. 4-K) and oil pumped down the annular space between casing and tubing through a sand filter with a walking beam type pump. The gas/oil ratio was immediately reduced to 250 while oil production was 42 B/D. It will be noted that gas/oil ratio was 4,200 at this packer level with mud in the annulus (Fig. 4-G). This well has produced with low gas/oil ratio for slightly more than two years with packers at this level. Less than 1 bbl of oil per day has been supplied to the casing on the average.

Tests previously conducted using a sand and gravel filled test cell indicated that 16 bbl of oil per day would have been required if the condition and laws of flow of the coning path had approximated that of the test cell. Using a cell containing a 6 in. sand column, a rate of flow of 1 bbl of oil per day resulted with an upstream pressure of 550 psia and atmospheric downstream pressure. For the same conditions the rate of gas flow as measured at 14.7 psia and 60°F was 6,000 cu ft per day. This suggested an oil/coning gas ratio of 1 bbl of oil for each 6,000 cu ft of coning gas for a bottom hole pressure of 550 psia. The oil/gas ratio would, of course, decrease as bottom hole pressure increases since the reservoir volume occupied by a given volume of gas will decrease as the bottom hole pressure increases.

It was discovered that the gas section ultimately quit taking oil under hydrostatic head of the oil column even though filtered oil was being pumped down along supposedly clean casing and tubing surfaces. The gas/oil ratio also started rising at this time. The packers were raised out of the liner and flow secured from the entire sand section. Packers were then lowered to the previous level. The sand again took oil, and gas/oil ratio was again reduced to 250 cu ft per bbl.

Equipment

To prevent gas lock, 1-in. tubing is used for sucker rods, the oil coming up through the 1-in. and the gas rising in the annular space between the 1-in. and 2-in. tubing. A 4-in. OD chamber is provided around the seating nipple to permit the gas to by-pass the seating nipple and pump. A hollow polish rod was employed which has a slot for the oil to pass into a space between two packing glands which connects with lead lines. This construction avoids the use of hose connection as commonly used in this type of pumping.

Case 2

Fig. 5 shows results of an alternate layer completion on the north offset to the well just described. In this case the casing was purposely set about six ft above the gas-oil contact. Sixteen ft of

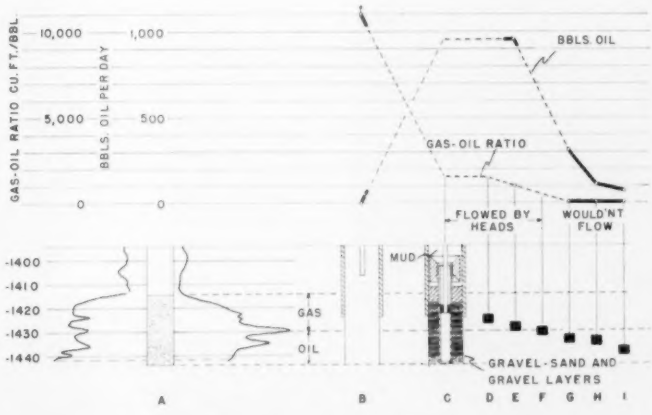

FIG. 5 — RESULTS OF ALTERNATE LAYER COMPLETION OF NORTH OFFSET.

the gas sand and 14 ft of oil sand were penetrated in this well.

The procedure originally planned for thoroughly cleaning the sand face was to allow the well to flow on a small choke until it headed up with oil and died. Sand was then to be cleaned out with a sand pump and the section gravel packed. The open hole section was underreamed to about eight in. with a cable tool underreamer to remove any cement sheath which might have been present on the sand face. However, when swabbed, gas flow without any trace of oil developed. Although the well was flowed for four days on a ¼-in. choke, no trace of oil was secured.

A temporary gravel pack was placed with coarse gravel filling the lower eight ft and alternate sand and gravel layers about this level. By setting packer just below the gas-oil contact, oil production resulted. The packer was then raised and the well flowed into the pit for 14 hours as a means of cleaning it. Oil production was about 550 bbl during this period, this being at the rate of approximately 950 B/D. The gas/oil ratio was not determined but was estimated as less than 2,000 cu ft per bbl. This low ratio partly resulted from the high rate of oil production.

The temporary gravel pack was then removed and that shown placed. The tests shown are by swabbing down for each packer position and then measuring the rate of fill up in the tubing by running the swab. The rate of fill up for a pressure differential of 400 psi was then calculated for each packer position. The gas/oil ratio was estimated by measuring the gas flow from the tubing during fill up.

One surprising result was that the gas volume was very greatly reduced by the gravel pack even without the use of the packer. This could be explained if it is assumed that most of the gas volume came down outside the casing due to faulty cementing. The path for flow would substantially be closed after gravel packing if sand production from the gas zone occurred filling this space with sand. Sand in the gas section below the casing was low in permeability and might not have been capable of producing a large gas volume.

Fig. 5, C to I, is a graphical representation of oil production and gas/oil ratio for various levels of the packer. Oil production for the three lowest packer positions ranging upward from the lowest level, was 75, 195, and 312 B/D respectively. The gas volume was negligible for these packer levels. Accurate measurement of fluid production by measuring rate of fill up in tubing was impossible for higher packer levels both because of high rate of fill up and the production of gas. The maximum rate of production was assumed to be that obtained on the previously mentioned test with a temporary gravel pack in place, that is, 950 B/D.

The above tests were made with the tubing-casing annulus filled with drilling mud. This mud was replaced with oil after about a year without backflowing to remove the mud filter cake from the gas section. About 20 gal of oil per day is required to keep the casing-tubing annulus filled.

The well has thus far produced approximately three years with this completion without appreciable change in gas/oil ratio or oil production. The packer has been positioned four ft above bottom during this time.

Case 3

Fig. 6 shows data on an alternate layer completion in the Oakville Field of Live Oak County, Tex. This well is near two wells which were abandoned about seven years ago after failure to shut-off gas and water by squeeze cementing after five squeeze jobs on each. One of these wells was 150 ft from the well on which data is shown and the other 330 ft from it.

Production is from the Pettus sand at a depth of 2,710 ft. The upper 28 ft of the sand section is gas saturated and the lower 10 ft penetrated oil saturated. Casing was set at the gas-oil contact. Bottom hole pressure is about 1,250 psi. To control pressure the hole was loaded with saturated brine while cleaning out and gravel packing, this well having been completed without the use of soluble mud. Tubing swab was run until the oil and gas flow occurred. Gas was then bled off through a small choke until sufficient oil flowed in to kill the well. Cavings were then cleaned out with a sand pump and alternate layer gravel pack placed. This completion is illustrated by Fig. 6-D. Brine was then replaced by drilling mud. The packer assembly was positioned so as to have its bottom point eight ft below the gas-oil contact (Fig. 6-E). Initial production was 50 B/D on 7/32 in. choke with a gas/oil ratio of 1,000 cu ft per bbl. Gas/oil ratio gradually rose. At the end of 10 days gas/oil ratio was near 2,000:1. Choke size was reduced to ⅛ in. Oil production was about 20 B/D on this choke. The gas/oil ratio continued to rise until at the end of 1½ months the ratio was near 10,000 cu ft per bbl.

After a shut-in period while waiting on equipment, the drilling mud in the annular space between casing and tub-

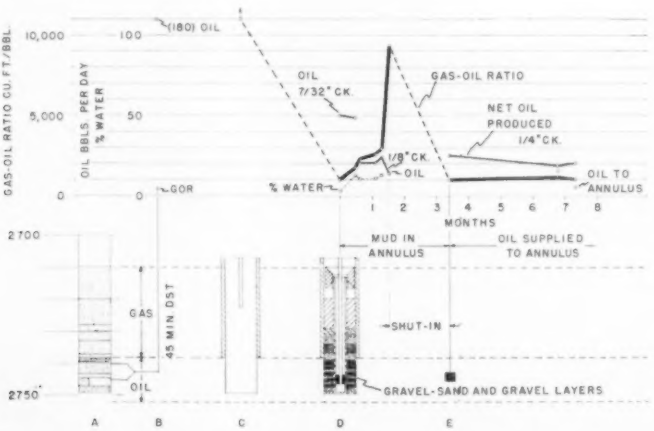

FIG. 6 — DATA ON ALTERNATE LAYER COMPLETION, OAKVILLE FIELD, LIVE OAK COUNTY, TEX.

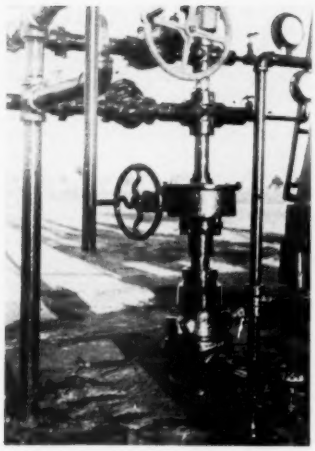

FIG. 7 — SURFACE PORTION OF BACKFLOW ARRANGEMENT.

ing was replaced with oil. Oil was supplied by a walking beam pump and pumped to the casing through a sand filter.

Oil injection into the gas section resulted in an immediate reduction in gas/oil ratio to approximately 1,000 cu ft per bbl. This value remained approximately constant for the six-month period during which it was closely observed. The last point on the gas/oil ratio and oil production curve is a 15-day average. During this time the oil supplied to the casing annulus has also been measured. Average value for the latter is five bbl per day.

Oil is continuously injected down the annular space between the tubing and casing. However a pressure relief valve is provided which results in oil flowing back to the stock tank if the casing fills. Oil supply to the casing is regulated by throttling of the intake line to the minimum amount necessary to control gas/oil ratio. Continuous flooding of the gas sand with oil does not occur because the sand face periodically plugs with scale and similar material. When oil flow into the sand stops, the oil which has been injected into the gas sand is produced and gas/oil ratio starts rising at which time the gas section is backflowed. Although oil is continuously supplied to the casing, flow into the sand is intermittent, the gas section thus being periodically cleared of oil.

BACK FLOW EQUIPMENT

Fig. 7 shows the surface portion of the backflow arrangement. A port is provided immediaely above the packer assembly which may be opened by rotation of the tubing allowing flow into the tubing from the annulus and from the sand section above the packer. This type packer assembly including the backflow port is shown in Fig. 8. The hand wheel (Fig. 7) rotates the tubing by means of a worm gear. The only change in connections required is that of disconnecting the flow lines. This type of backflow has the advantage that any material which has settled out of the fluid column in the annulus is also recovered as well as that filtered out on the sand face.

PUMPING EQUIPMENT

Pumping equipment was installed because the earlier well, 150 ft from this location, had a somewhat lower productivity index and would not produce the allowable by natural flow. Oil is supplied to the casing by the walking beam pump through a sand filter. A line from the pump suction leads to the stock tank into which the well produces through a gun barrel. Thus the stock tank gauge shows the net oil produced. To prevent gas locking, 1-in. tubing is used for sucker rods, the oil coming up through the 1-in. while the gas rises in the annular space between the 1-in. and 2-in. tubing. A 4-in. OD chamber is provided around the seating nipple and pump to permit the to by-pass this point. A hollow polish rod having a slot for oil to pass into a space between two packing glands which connects with the lead lines is employed.

After producing two years, the above well developed excessive water production as a result of edge water encroachment. It has now been recompleted at a higher level as a gas well.

SUMMARY OF FIELD USE

One hundred wells have been completed with the described type of gravel pack procedure to date. Sixty-five of these are in the Quien Sabe and North Albercas Fields of Webb County, Tex. One or more completions have also been made in Jim Hogg, Zapata, Duval, McMullen, Live Oak, Victoria, Fort Bend and Brazoria counties. Alternate layers have been used in 18 of the above, the gravel pack in the remainder being composed of uniform gravel.

Double packers were run in three of the alternate layer completions. A water shut-off was obtained in two of these; water production was reduced by about 50 per cent in the other. In the latter case only four ft of sand was present above the water level. A complete fluid shut-off could be obtained in this case, however, when packer was raised above the top of the sand section.

Single packers were run for shutting-off gas in case of 12 alternate layer completions. All of these were initially tested with the annular space between the casing and tubing filled with drilling mud or with at least the bottom of the fluid column composed of drilling mud. In all cases an initial gas shut-off was secured. This includes two recent cases in which the lower two ft of a

FIG. 8 — PACKER ASSEMBLY FOR SHUTTING OFF UPPER PORTION OF SAND SECTION.

35 ft sand section was oil saturated while the upper 33 ft was gas saturated. In two completions high gas/oil ratio later developed evidently as a result of vertical coning. In these cases gas was successfully controlled by continuous injection of oil into the gas sand.

Failure resulted in six of the above 100 cases because initial plugging of the gravel pack. Most of these cases occurred during the early use of this procedure and before the development of soluble mud. Three of these cases were on old wells having large cavities All obviously resulted from inadequate clean out procedure, the plugging appearing to be due to a layer of cavings or filtered out material between the gravel and sand face.

Five cementing failures also occurred in the above 100 cases. This, of course, refers to failure of the cement around the liner which holds the gravel pack in place. All except two of these wells were successfully recompleted. No attempt at recompletion was made in these two cases. Cementing failure appeared to be principally due to dilution of cement while dumping. A cementing technique has since been developed which would have avoided most failures.

CONCLUSIONS

In conclusion, the advantages to be gained by this completion procedure may be summarized as follows:

1. A positive method for shutting off gas and water is provided.
2. The producing level may be easily changed at any time. The optimum producing level may be determined after completion. This makes the following unnecessary:
   a. Exact information as to the location of the gas-oil or oil-water contact.
   b. A preliminary guess as to the extent of vertical coning.
   c. Dependence upon the gas-oil or oil-water contact remaining at the same level.
   d. Precise depth measurement.
3. Complete sand screening is achieved, and
4. A method for controlling vertical coning is provided.

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DISCUSSION

By Bruce Barkis, B&W, Inc., Houston, Tex., Member AIME

Gravel packing for the control of sand entry in unconsolidated sand fields has been an accepted practice for some years. Current usage of fine gravels in the size range reported by West, clean placement fluids of the heavy brine type, and improved tools for gravel placement are responsible for the higher percentage of successful jobs of this type.

West's report of the usage of alternate layers of fine gravel and sand, aided by mud or oil seals, to control gas and oil entry in the open hole and lower pressure in completions of South Texas indicates that gas/oil ratio control can be accomplished in a fairly thin vertical section by materials providing a fairly low differential pressure.

A large percentage (90-95 per cent) of the wells which are gravel packed on the Upper Texas and Louisiana Gulf Coast are old producers. Almost every one of these wells has been completed through gun perforations in 5-20 ft sand sections. Assuming an average 10 ft perforated section with 6½-in. hole per ft, results in only about 12 sq in. of drainage opening. The difficulty of cleaning the surface of such small sand exposure, and of keeping it clean during the placement of the gravel, coupled with the additional complication of high fluid entrance, because of the small drainage area, suggests that large increases in sand exposure, by jet shooting or cutting, milled out sections or other form of window completion, would provide the amount of sand surface necessary for satisfactory gravel formation contact.

Sand production, in an oil well, and the velocity of the entering fluid are closely related. Further assuming a fluid production of 60 B/D, from the above section, or an average of one B/D ½-in. hole results in an entrance velocity of 7.2×10^2 ft/sec and according to Gumpertz, sand production at such velocity can easily be expected. This data further suggests that increased sand exposure is very desirable.

★ ★ ★

The Drift of Things

. . . as followed by EDWARD H. ROBIE
Secretary AIME

Every year new words, phrases, or methods of expression rise to temporary fame. Such, for example, was the word "normalcy," popularized by President Coolidge. A year or so ago we mentioned the new vogue for "presently" instead of "currently," presently having formerly meant pretty soon instead of right now.

A few years ago *Time*, we believe it was, began writing $8 million instead of $8,000,000, and the practice of expressing large sums in this way has spread to most newspapers and magazines. We presume the reason for this style was to avoid a row of ciphers; there being no saving in the space used. We still are not sure just how this should be read. Are we supposed to read it eight million dollars, or eight dollars million? If the former, then what do we do when the $8 comes at the end of a line, or column, or page. You see the $8 but your eye has to travel elsewhere to see the million. A well-known columnist puts it this way: 8 million $, which makes more sense, if one can get used to seeing a dollar sign alone.

Perhaps the most noticeable comet in the present linguistic sky is the common use of the expression "as of." This originally was legal jargon, and confined to financial reports and such where it sometimes had a useful significance. But now we read in the paper, "Unfilled orders as of Dec. 31 were $91,260,000." Why not use on? In a news letter, "The cost-of-living index made a new all-time high as of Feb. 15." Why not "The Feb. 15 cost-of-living index . . .?" And the radio: "As of right now, the forces of nature seem to be under control." Why the as of? Also, "The Jersey Central is shutting down service as of 1 o'clock tomorrow." Why not say at? In "All About Eve," "As of this moment, you are six years old." Again, why not at? And in the U. S. Steel report, "U. S. Steel's ingot capacity has been increased to give a total annual capacity, as of Jan. 1, 1951, of 33.9 million tons." Why not say on?

Another adaption of the last few years is use of the word "defense" instead of "military" or "war preparation." Good psychology is back of this euphenism. No one can object to defense of the country, but everybody is fed up with war as a means of settling international difficulties.

We suggest that those who use this bit of frippery unconsciously think they are utilizing one of the super niceties of expression. As a matter of fact, 99 times out of a hundred, they are using a clumsy phrase that could better either be omitted entirely or be replaced by one two-letter word.

Men Wanted

In the employment situation for professional men in the mineral technology field, the pendulum seems to swing rapidly and far. Less than a year ago more men were seeking jobs than there were openings available. This was particularly true of young men and inexperienced college graduates. Just the reverse is now true. The Engineering Societies Personnel Service reports that it has recently been able to find men for only 7 per cent of the openings that it has available. In more normal times the figure is 35 or 40 per cent. Those who might be interested in considering another job therefore might find it to their advantage to register with the Personnel Service. Also, they would thereby make it possible for the Service to do a better job of filling requests from employers.

The Personnel Service has four offices. One should register with the office that serves the area in which a job would be most attractive. Registration with more than one office is permissible. Western mining and oil men would naturally clear through the San Francisco office; most metallurgists through one of the Eastern or Mid-Western offices. The addresses are: 8 W. 40th St., New York 18; 100 Farnsworth Ave., Detroit; 84 E. Randolph St., Chicago 1; and 57 Post St., San Francisco. There is no charge for registration — only if a job is secured. The fee for AIME members is one week's salary for jobs paying less than $3,000 a year, ranging up to 3¾ per cent of annual salary for jobs paying $5,000 or more. A registrant is kept on the active list for two months. If a job is not secured in that time, he may on request be kept on the active list longer. If a job is secured but not accepted there is no charge.

All jobs are coded, so no publicity is given to a registrant except to the potential employer to whom the registrant is referred and who has asked for a man with his type of experience.

Bargain for New Junior Members

Never before, we believe, have newly elected Junior Members of the AIME received such a bargain as they are now getting. Graduating Student Associates are being given a special incentive to change their status to Junior Membership and young men out in the industry, not over 30 years old, who are not yet members will probably never have a better incentive to apply.

Beginning with elections in May, 1951, all new Junior Members are privileged to receive a copy of the immensely popular reprint of *Agricola*, some 2,500 copies of which have been ordered by AIME members since the volume was issued early last December. The stock was soon exhausted but more are now available. This is a $10 book, with no discount permitted. The Institute however has purchased, through money made available by the Seeley W. Mudd Memorial Fund, a total of 1,400 copies for distribution to new Junior Members gratis. Also they automatically receive a copy of *A Professional Guide for Junior Engineers* and their choice of one of seven other volumes ranging in price from $1.50 to $5. If their interests happen to be in petroleum they also receive a fourth free volume, listed at $2.50, on the legal aspects of the unit operation of oil pools. Thus, for the initial year's dues of $12 (there is no initiation fee), a Junior Member receives a year's subscription to the journal of his choice and up to $18.50 worth of books.

The opportunity to purchase books at special prices is an advantage that all members receive, but is not always realized. Books published by one of the Institute's Funds are available to members at approximately half the price that a commercial publisher would place on a similar book. Also, AIME members are granted a 10 per cent discount on a wide variety of other books. For those who keep their libraries up to date and well stocked the savings thus possible may offset the annual dues. ★ ★ ★

E. N. Van Duzee
For Executive Committee

Morris Muskat
For Vice-Chairman

Paul R. Turnbull
For Chairman

John R. McMillan
For Vice-Chairman

G. L. Yates
For Executive Committee

Nominees for Petroleum Branch Offices, 1952

The Branch Nominating Committee, composed of John E. Sherborne, chairman, R. M. Churchwell, Harold Decker, Paul E. Fitzgerald, and Fred E. Simmons, Jr., has nominated the members pictured on this page for positions in the Branch government. Article IX of the By-laws calls for publication in June of the pictures and biographies of these nominees. Any group of 10 members may submit additional nominations until August 15. A letter ballot, covering all positions to which the membership has submitted nominations, will be mailed in September. If there are no nominations from the membership by August 15, the letter ballot will be dispensed with and the Committee's nominees will be declared automatically elected. The new officers will be installed at the 1952 Annual Meeting in February.

For Chairman

PAUL R. TURNBULL, at present a vice-chairman of the Branch, received his BS degree in petroleum engineering from the University of Oklahoma in 1929. He joined Humble Oil and Refining Co., with whom he worked in West Texas, East Texas, and Southwest Texas for 19 years. In August, 1946, he became division petroleum engineer for Humble's Southwest Texas Division at Corpus Christi. Since September, 1949, he has been manager of drilling and production for the La Gloria Corp. in Corpus Christi. From 1942 to 1945 he served in the U. S. Air Corps, rising from second lieutenant to major. Active in the AIME for 15 years, he served as the first chairman of the Southwest Texas Section in 1947 and was the section's delegate to the Annual Meeting. He was elected a director of the section in 1948. He was appointed vice-chairman of the Production Technology Committee in 1949, and acted for the chairman in arranging the program for the Fall Meeting of the Branch in San Antonio.

For Vice-Chairman

MORRIS MUSKAT attended Marietta College in Marietta, Ohio, and Ohio State University in Columbus, where he received his BA and MA degrees in 1926. Having majored in physics, he instructed physics and chemistry classes at Bowling Green University for one year. Additional graduate study at California Institute of Technology earned him a doctorate in 1929. He joined Gulf Research and Development Co. as a physicist, and in 1935 was appointed director of the physics division of that company. In 1950 he was transferred to the Gulf Oil Corp. as technical assistant to the vice-president in charge of production. Muskat is the author of *Flow of Fluids Through Porous Media* and *Physical Principles of Oil Production*, as well as a number of technical publications. As chairman of the Petroleum Branch Production Technology Committee during 1950 he was in charge of the selection of technical papers presented at the Fall Meeting in New Orleans.

For Vice-Chairman

JOHN R. McMILLAN received his early education in the public schools of Los Angeles, Calif., where he moved at an early age from his birthplace in Vermont. After attending the University of California at L. A., he transferred to California Institute of Technology where he received a BS degree in 1931. During the next 12 years he held various positions with the Barnsdall Oil Co., from production roustabout and draftsman to production foreman, and for the last six years of this time was in the land and geological department. He joined the Fullerton Oil Co. in July, 1943, as petroleum engineer, and later became manager of field operations. Since June, 1947, he has been vice-president in charge of production and a member of the board of directors. He has been council member and chairman of the Pacific Petroleum Chapter of AIME, executive committee member of the Southern California Section, and a member of the Branch Executive Committee for two years. He is also active in the AAPG, the API, and the Petroleum Club of Los Angeles.

For Executive Committee

E. N. VAN DUZEE was born in St. Paul, Minn., and served for a short time in the Air Corps during World War I. In 1926, he graduated from the University of Minnesota with a degree of Engineer of Mines. Joining the Roxanna Petroleum Corp., forerunner of the Shell Oil Co., with whom he is now employed, he spent seven years in West Texas and New Mexico as field engineer, district exploitation engineer and district foreman. He became district superintendent at Iowa, La., in 1933, and later was transferred to the Black Bayou Field of Southwest Louisiana. After a year as manager of the Oklahoma Division, he returned to Lake Charles, La., as manager of the Louisiana Division. Since 1946 he has been production manager of the New Orleans area. During 1949 he was vice-chairman of the Delta Section of AIME, and is now a director of the section. He is also vice-chairman for South Louisiana of the Southwestern District of API.

For Executive Committee

G. L. YATES began his career in the oil fields of Kansas and Oklahoma, during the summers between sessions at Lehigh University and the University of Oklahoma. He received a BS in petroleum engineering in 1934 and his MS in mechanical engineering in 1935. For the next eight years, he taught in the Department of Oil and Gas at the University of Pittsburgh. During interim summers, he was special engineer for the Phillips Petroleum Co. After a short period with the Kingwood Oil Co., he joined the production department of Standard Oil Co. (Ohio) in Cleveland, in 1944. He became head of the evaluation engineering section, and held that position until November, 1947. At that time he entered a partnership with P. T. Amstutz, under the firm name of Amstutz and Yates, consulting petroleum engineers and geologists. He was a delegate from the Kansas Section of AIME to the last annual meeting, and is now chairman.

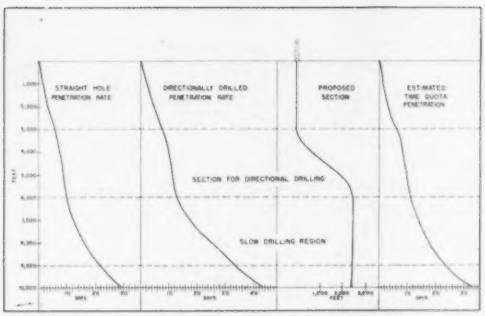

FIG. 8 — DATA SHOWING DEFLECTION IN 3,000 - 6,000 FT SECTION.

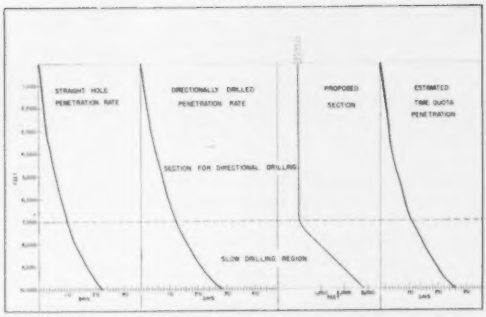

FIG. 9 — DATA SHOWING DEFLECTION IN LOWER PORTION OF WELL.

Directional Drilling

(Continued from Page 17, Section 1)

then the well should be planned to be deflected as shown in Fig. 8. The deflection work would be undertaken in the section from 3,000 to 6,000 ft and straight hole drilled in the deeper sections where directional drilling was known to be slow. The estimated time for drilling in this manner is considerably faster than the directional plan which would include directional work below 6,000 ft. The proper importance must be given to considerations involving the drift angle, the deflected distance, etc., in order to pick and use the most economical section in which to do the deflected drilling. Many times the overall drilling time will be lower if higher drift angles are used and the needed deflection can be gained while drilling through the most ideal formations for slanted drilling. Many times drift angles of 20 to 40 degrees are much more economical than angles of 5 to 10 degrees. With the proper casing program the type of directional job shown in Fig. 8 is very feasible and has been successfully accomplished many times in many different areas in the Gulf Coast and Pacific Coast regions.

On the other hand, if the drilling rate at the bottom of the hole is reasonably fast, the best system is to drill the top straight to take advantage of the high speed in the upper portion of the well and then start deflection lower and carry higher drift angles as shown in Fig. 9. Some of the largest savings in rig time have been made by doing the directional work in the lower portion of the well bore. Higher drift angles ordinarily permit faster penetration and also require a lesser number of deflection tool runs. The well bore will stay on course and greater weight can be applied to the bit if higher drift angles are utilized.

When the whole geological section is uniform in its reaction to directional drilling operations, the controlling factors in choosing the proper starting and stopping points for deflection work are the drift angle and the distance which the well has to be deflected. All things being equal, the total amount of deflection work can be governed by raising or lowering the drift angle.

If the actual well data is not available on either slanted or straight hole in the area in which a directional job is to be undertaken, it is entirely feasible to construct expected rate curves and use them in the planning phase of the job. There have been numerous instances where this has been done, and it is surprising the benefits which have been gained by actually estimating drilling times and setting up a time quota before the job was begun.

ACKNOWLEDGMENTS

The author wishes to take this opportunity to express his appreciation to the Eastman Oil Well Survey Co. for permission to prepare and present this paper, to Earl M. Kipp and R. B. McCloy for their critical review and suggestions, and to the helpful cooperation of the oil companies who supplied the information necessary for this paper. ★ ★ ★

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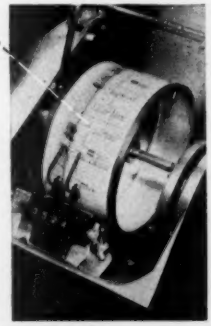

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Chemical Service

Continued from Page 22, Section 1

treatments can be controlled with no difficulty, and that packers may be set effectively without danger from bypassing through fractures or other openings created in the rocks by the force of the explosion. Also, it should be possible to flood tight formations at an economic rate with pressures that are sufficiently moderate so as to avoid pressure parting of the formation. Further field tests of this form of treatment are justified.

Recent laboratory research on oil recovery by water flooding, using California reservoir material, has shown remarkable reduction in residual oil content as a result of the addition of very small quantities of non-ionic ethylene oxide condensation products to the injected water. The results obtained from these laboratory tests have been so promising that an experimental field test was commenced in April in a California field, and another test in California is contemplated in the very near future. Extensive laboratory work is being planned for further study of the reaction of reservoir rocks from other important oil-producing regions to this form of treatment.

The effect of non-ionic surface active compounds should be distinguished clearly from the generally unsatisfactory experience that has been obtained from attempts to use many anionic compounds, such as soaps, alkyl sulfates, alkyl aryl sultonates, and many other types of synthetic detergents, which tend to become adsorbed quickly on reservoir surfaces, particularly those where a predominance of basic radicals are present. These non-ionic compounds have maintained their surface active properties after long periods of contact with pulverized oil sands. In laboratory tests they have shown negligible tendency to become adsorbed by siliceous or clay minerals.

Many oil wells, in both primary and secondary recovery operations, cannot be produced profitably because of excessive production of water, even though considerable sections of the reservoir which possess lower average permeability have not been depleted of their oil content. The possibilities for creation of water repellant surfaces in oil reservoir rocks in order to retard or stop water encroachment have been recognized for many years, and various substances are known which will cause a temporary change in the nature of the surface. Since frequent repetition of treatment was required these treatments have not been profitable.

Recently, it has been discovered that certain complex nitrogeneous compounds will produce hydrophobic surfaces on oil reservoir rocks which have maintained their properties in the laboratory for a period of over nine months. The sand samples that have been treated with this reagent have been washed repeatedly with both fresh and saline water with no apparent diminution in their pronounced hydrophobic tendencies. Furthermore, no resistance to the flow of oil has developed, which is of great importance where an effort is to be made to obtain the very maximum oil recovery. Laboratory experiments in the use of this and other similar reagents are being continued. It is indicated that a variety of chemicals and chemical combinations may be required for the effective treatment of the diverse conditions that characterize oil reservoirs and reservoir fluids.

The partnership of Oil Recovery Chemicals is in process of organization. The business of the company will be to study oil production problems for which various forms of chemical treatment may provide a solution, and to provide the necessary service connected with the application of the indicated treatment. It is, also, proposed that the company will have its headquarters at Austin, Tex., where complete laboratory facilities will be provided for the study of applications of chemical treatments to oil reservoirs, and where an adequate stock of all chemicals will be maintained. Research in the development of new compounds and new techniques will be continued in other laboratories by patent-holders and by chemical manufacturers.

REFERENCES

1. Weber, George: *Oil and Gas Jour.*, (Jan. 25, 1951), 171-172. ★ ★ ★

— It's a Fact —

Taxes on the typical motor vehicle and the gasoline it used last year added up to almost as much as the average motorist paid in federal income taxes.

Five Awards to be Given By AIME in 1952

The AIME Board of Directors has authorized the granting of five awards at the Annual Meeting in 1952. The name of the award, the purpose for which granted, and the name of the chairman of the committee appointed to select the recipient, follow:

Charles F. Rand Medal for distinguished achievement in mining administration, the term mining to be broadly interpreted to include metallurgy and petroleum. Eugene Holman, chairman Rand Medal Committee, Standard Oil Co. (N.J.), 30 Rockefeller Plaza, New York 20, N. Y.

The Mathewson Medal for the Institute of Metals Division paper which represents the most notable contribution to metallurgical science in the three-year period preceding the award. C. E. Nelson, chairman Mathewson Medal Committee, Dow Chemical Co., Midland, Mich.

Robert H. Richards Award to recognize achievement in any form which unmistakably furthers the art of mineral beneficiation in any of its branches. H. A. Pearse, chairman Richards Award Committee, Howe Sound Co., 730 Fifth Ave., New York, N. Y.

Robert W. Hunt Award for the best AIME paper on iron and steel. T. L. Joseph, chairman Hunt Award Committee, University of Minnesota, Minneapolis, Minn.

J. E. Johnson, Jr., Award to a man under 40 who has exhibited exceptional ability in research, invention, or contributions to the technical literature related to the metallurgy or manufacture of pig iron. Paul R. Nichols, chairman Johnson Award Committee, Wisconsin Steel Works, South Chicago, Ill. ★ ★ ★

AIME to Publish Three New Volumes

Three special volumes to be published within the next year or two by the AIME under the sponsorship of the Seeley W. Mudd Memorial Fund and the Henry L. Doherty Memorial Fund have been authorized.

The first of these to be published, since it is now in galley form, will be the second edition of *Basic Open Hearth Steelmaking* which should be available within a few months. The second to appear will undoubtedly be *Petroleum Conservation*, edited by Stuart E. Buckley, the manuscript of which has now been completed. This is sponsored by the Doherty Fund. Third, is a new edition of *The Marketing of Metals and Minerals*, a book first published a quarter of a century ago which has long been out of print. F. E. Wormser, one of the original authors, now vice-president of the St. Joseph Lead Co., and Simon D. Strauss, vice-president of the American Smelting and Refining Co., will collaborate on the new edition. Authorization to proceed with the work was voted at the meeting of the Board of Directors on April 18. ★ ★ ★

— It's a Fact —

Missouri, Georgia, New Mexico, Nebraska and North Dakota reduced gasoline taxes in the past year saving motorists more than $33,000,000 yearly.

Current AIME Budget Shows $6,430 Surplus

At the April meeting of the Board of Directors the final budget for the current year, showing a surplus of $6,430, was adopted. Total income is expected to be $502,700, compared with $493,689 in 1950; expenses, $496,270, compared with $511,411 in 1950. The budget is believed to be conservative, based on present costs.

Last year the Metals Branch had a deficit of close to $42,000, its expense for publications being over $119,000. This has been cut down in the 1951 budget to $102,630 for publications, the Branch deficit being reduced to $13,437. This promises to be the last year that the Metals Branch will suffer a deficit. Advertising income in the *Journal of Metals* is showing a healthy increase, justifying the money that was put into the journal to get it established. Its net advertising income in 1949 was $11,000; in 1950 $30,000; with $45,000 budgeted in 1951.

The Mining Branch expense for 1951 includes for the first time an appropriation for the Western Secretary and the expenses of his office, amounting to $12,000. If there should be a deficit in AIME accounts for the year, the Rocky Mountain Club Fund has promised to meet it up to this $12,000 figure, thus adding an extra factor of safety to the budget.

For the first four months of 1951, AIME income was $336,610, or $27,428 in excess of the same period in 1950. Expenses were $184,642 or $14,721 less than in the same period last year. Thus the Institute completes the first third of the year with an improvement over its financial position of a year ago by $42,149. ★ ★ ★

Syria Welcomes Aid From U. S. Oil Companies

The Syrian Minister to the United States has requested the assistance of the U. S. Government in advising private U. S. oil companies that their interest in oil exploration in Syria would be welcomed. The Syrian Minister stated that the present concessionaire, the Syrian Petroleum Co. (subsidiary of the Iraq Petroleum Co.), was abandoning its work as of August 15 after which date the most favorable area in Syria would be available for competitive bidding.

Successful gas wells have been drilled near the Iraq border and this section, bordering the rich oil lands of Iraq, is geologically a part of the Persian Gulf basin, the richest oil section of the earth's crust.

For further information get in touch with the Syrian Legation, 2215 Wyoming Ave., N.W., Washington, D. C., or Syrian Government authorities in Damascus. ★ ★ ★

— It's a Fact —

The federal gasoline tax of 1½ cents per gallon now costs taxpayers more each year than the total tax receipts of the national government from all sources 35 years ago.

19th Geological Congress To Be Held in Algiers

The First Circular concerning the 19th International Geological Congress, to be held in Algiers in 1952, is now available. The Secretary, AIME, has a small supply of the circulars and will send a copy to any AIME member as long as the supply lasts. Or copies may be secured direct from R. Lafitte, General Secretary of the Algerian Organizing Committee, Faculté des Sciences, Alger (Algeria). ★ ★ ★

THESE FAMOUS
Eastman
OIL WELL SURVEY
INSTRUMENTS
FOR RENT
SINGLE SHOT SURVEY INSTRUMENTS
REGULAR TYPE—This instrument is favored because of its simplicity of operation. The Drilling crew can load, unload, and develop the recording discs in daylight. The discs are easy to read and simple to interpret. It is the most dependable survey instrument available.
SMALL TYPE—This instrument is used with retractable coring equipment, with non-magnetic drill collars, or special trigger bits. Its use results in substantial savings in rig time. The operation is identical to that of the regular type instrument.
THESE INSTRUMENTS ARE USED—
1 On all directional drilling operations for checking the course of the well.
2 To accurately record the course of the well as it is drilled in order to straighten the bore if necessary.
3 As a means of securing information to insure correct bottom hole spacing on the lease.
4 For determining the correct location of all points in the well in reference to the geological structure.
5 In orienting cores to correct for the true drift and deviation of the well bore.
DRIFT INDICATORS
TYPE "W" DRIFT INDICATORS — The Type "W" is a mechanical instrument which eliminates the use of batteries, light bulbs, and photosensitive discs. The instrument incorporates a patented self-checking design which enables it to make two recordings. This feature insures that an incorrect reading will not be accepted.
TYPE "M" DRIFT INDICATOR—This instrument records photographically. Due to the length of the exposure necessary to make a recording, the operator is assured of a true reading. If the instrument's plumb bob is in motion, no record is obtained.
THESE INSTRUMENTS ARE USED—
1 To determine that the well is drilled within the drift limits specified in the contract.
2 As an assurance that there are no "doglegs" left in a straight well after it is drilled.
3 For economy. They are the most inexpensive straight-hole surveying instruments available.
4 In drilling a well on a flat structure to assure that the hole is moderately straight. After drilling is completed a Multiple Shot Survey is run to determine the exact course of the well.
CALL THE EASTMAN MAN NEAREST YOU!
(Consult Your Telephone Directory)
EASTMAN OFFERS YOU DEPENDABLE INSTRUMENTS, SERVICE AND RESULTS
These instruments are rented to operators and drilling contractors, complete with supplies and accessories. Frequent calls are made at the well by Eastman Service Men to insure satisfactory operation of the equipment.
EASTMAN OIL WELL SURVEY CO.
LONG BEACH
DENVER
HOUSTON

Personals

J. French Robinson recently assumed the presidency of Consolidated Natural Gas Co. of New York. He will retain the board chairmanship of East Ohio Gas Co., one of five companies owned by Consolidated. Robinson was born in 1890 in Elizabeth, W. Va., and as a youth read meters and repaired gas lines for his father, who owned a small gas company. He was with the People's Natural Gas Co., another Consolidated subsidiary, before joining East Ohio in 1940. Robinson will maintain residence in Cleveland, though his offices were transferred to New York.

+

William G. Abbott has been transferred to the Amerada Petroleum Corp. Fort Worth, Tex., office as petroleum engineer. He was formerly district engineer at Big Lake, Tex.

+

Sam T. Boltz is now a roustabout engineer for The Texas Co., Caldwell, Tex.

+

L. G. Chombart, well log consulting engineer, has joined Amstutz & Yates, Inc., consulting petroleum engineers and geologists, Wichita, Kans. His consulting services for detailed analysis and review of well logs of Kansas and other states will continue to be available through the firm. Another phase of his work will involve extensive use of well log data in the firm's consulting work on completion and production problems, estimates of reserves, etc. His experience includes 14 years with Schlumberger Well Surveying Corp. in various capacities, including managership of the Kansas Division, and several months of well log consulting work with a Tulsa associate, R. G. Hamilton.

Edward C. G. Borrego, Tropical Oil Co., has been made general manager and is now located in Bogota, Colombia.

+

John Patrick Conroy is now petroleum engineer with the Arabian American Oil Co., New York, N. Y.

+

Georges X. Calleya has joined the Mexican American Independent Co., Mexico, D. F.

+

William D. Carson is now with the Continental Oil Co., Ponca City, Okla.

+

R. G. Hamilton of Tulsa has reorganized his original firm of Hamilton Well Log Consultants, which now offers world-wide evaluation and consulting services in well logging and electric log interpretation for oil companies. His firm was organized in 1949.

The firm will distribute the new Arps-Hamilton Loganalyzer, a pocket-size slide rule condensing log quantitative relationships into a practical, easily operated calculator for obtaining porosity, water and oil saturations and permeability from electric logs. Hamilton was associated with the Schlumberger Well Surveying Corp. for 15 years and recently with L. G. Chombart under the firm name of Hamilton and Chombart.

+

Howard A. Johnson, Shell Oil Co., Great Bend, Kans., has been transferred to the Oklahoma City office.

+

John H. Jennings, formerly with Ohio Oil Co., Tulsa, is now with Deep Rock Oil Corp., Tulsa.

+

Seth L. Lobdell is now employed as company geologist by Hydrocarbon Storage, Inc., Fort Worth, Tex.

Ray C. Lewis, formerly chief geologist for the Houston Oil Co. of Texas, has been appointed to the newly created position of manager of exploration in charge of the geological, geophysical and land departments. Lewis is a graduate of the University of California. He served in various capacities in the geological department of Stanolind Oil and Gas Co. prior to joining the Houston Oil Co. of Texas in July, 1945.

+

Charles Robert Olson has become petroleum engineer for the Ohio Oil Co., Shreveport, La.

+

Michael Patrick Swingle has joined the Shell Oil Co., Tulsa.

+

Edgar C. Winegartner is now with the Humble Oil Co. of Baytown, Tex.

+

Milton H. Standley is now junior exploitation engineer, Shell Oil Co., Houston.

+

Richard V. Stauble is associated with the Socony Vacuum Oil Co., Caracas, Venezuela.

+

D. V. Carter has been elected a member of the Texas-Delta Chapter of Tau Beta Pi. Initiation ceremonies were conducted May 2, 1951, at College Station, Tex.

Meetings of Interest

The American Society for Testing Materials will hold its 54th Annual Meeting at Chalfonte-Haddon Hall, Atlantic City, N. J., June 18-22. Technical symposiums will be conducted on flame photometry, structural sandwich construction, acoustical materials, consolidation testing of soils, surface and subsurface reconnaissance, bulk sampling, and ultimate consumer goods. The complete provisional program may be obtained from ASTM, 1916 Race St., Philadelphia 3, Pa.

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 408 Trinity Universal Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to the positions coded Y5384 and Y5204 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

The Engineering Societies Personnel Service, Inc., has many outstanding engineering positions available throughout the United States and for foreign service.

Make your availability known to the office of the Engineering Societies Personnel Service, Inc., nearest to your home. Never before in the 30-year history of the Service have there been greater opportunities for members of the engineering profession in all branches, mechanical, electrical, civil, mining and metallurgical, chemical, naval architecture, etc.

Now is the time to find the opportunity you have been waiting for — but the initial step must be taken by you.

Alfred H. Meyer
Executive Director

New York
8 W. 40th St.
San Francisco
57 Post Street

Chicago
84 E. Randolph St.
Detroit
100 Farnsworth Ave.

POSITIONS

♦ A principal New York City banking establishment is seeking a graduate in petroleum engineering or petroleum geology, preferably one with several years' experience in field engineering and with some practice in valuation of oil and gas reserves. This position offers experience in oil and gas research studies and property appraisals as well as the correlative advantage of experience in the field of financing and the financial aspects of the petroleum industry. Financial stability and probability of advancement are excellent. Code 529.

♦ A college in the Southwest has an opening for a man to teach courses in petroleum production. He should have a BS degree and several years of practical experience. The rank and salary will be based upon the training and practical experience of the man employed. Opportunities for research as well as consulting work. Code 530.

♦ Chief geologist, assistant geologists and geophysicists for bringing into production new properties in Bolivia. Will examine prospects and attempt to find completely new mines. In addition to tin and base metals, attention will be paid to non-metallics as well as minerals not generally recognized by average prospectors. Salary open. Y5384.

♦ Lubrication sales engineer, 32-40, with experience in sales of industrial and automotive lubricants, to sell lubricating oils and greases throughout Latin America. Considerable traveling. Must have knowledge of Spanish. Salary, $7,200 a year plus expenses. Y5204.

PERSONNEL

♦ Graduate petroleum engineer, 30, married, eight years' varied petroleum industry experience, desires responsible position as executive assistant or situation offering advancement commensurate with performance. Available on 30 days' notice in Chicago area. Will relocate. Code 146.

♦ Available to operator or small company superintendent. Graduate petroleum engineer with more than 20 years' experience in drilling and production. Code 147.

♦ Production engineer wishes to change employment. MS in petroleum engineering with three years' experience. Married, three children, 29 years old, veteran of the last war. Code 148.

♦ Petroleum engineer, 1947 graduate, wishes to change employment. Want active position pertaining to drilling, completion and production. Prefer to work for independent producer. All offers considered. Age 31, married. Code 149.

Proposed for Membership, Petroleum Branch

Total AIME membership on January 31, 1951, was 17,228; in addition, 4,613 Student Associates were enrolled.

ADMISSIONS COMMITTEE

Thomas G. Moore, Chairman; Carroll A. Garner, Vice-Chairman; George B. Carless, F. W. Hanson, Albert J. Phillips, Lloyd C. Gibson, R. D. Mollison, John T. Sherman. Alternates, A. C. Brinker, H. W. Hitzrot, Plato Malozemoff, Ivan Given, T. D. Jones, W. H. Farrand.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend privileges but does not desire to admit persons unless they are qualified. Objections on applications should be received on the 15th of the month following publication in PETROLEUM TECHNOLOGY.

In the following list C/S means change of status; R, reinstatement; M, member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

CALIFORNIA

Bakersfield — Jarrett, James C. (M).
Los Angeles — Luckett, William E. (M).
Ventura — Schuppert, Richard R. (J) (R, C/S-S-J).
West Covina — Lloyd, Donald D. (J) (R, C/S-S-J).

COLORADO

Denver — Chabas, Paul D. (M).

ILLINOIS

Forrest Park — McEfee, Rene I. (M).

KANSAS

Chanute — Pate, Carl L. (M).
Lawrence — Weinaug, Charles F. (M) (C/S-J-M).

KENTUCKY

Owensboro — Davidson, Charles D. (J). Geissler, Paul M. (M) (R,C/S-S-M).

MISSOURI

Kansas City — Silberberg, Alfred H. (J) (R,C/S-S-J).

NEW MEXICO

Artesia — Chain, John H. (J) (R,C/S-S-J).

OKLAHOMA

Bartlesville — Smotherman, Harold M. (J).
Tulsa — Smith, Aurel E. (M) (C/S-A-M).

TEXAS

Andrews — Dingle, William W. (J).
Bishop — Cozad, David J. (J).
Dallas — Madera, Ruford F. (M); Metzger, Herbert A. (M); Nichols, Earl A. (M) (C/S-J-M); Tennant, Robert H. (M) (C/S-J-M).
Delmita — Gabel, George C. (J).
Fort Worth — Bonner, Bobby J. (J).
Houston — Spain, Horace H. (M).
Kermit — Barney, Charles L. (J); Puckett, James R. (M) (C/S-J-M).
Lake Jackson — Henson, Robert A. (M) (R, C/S-S-M).
Midland — Knox, John A. (J).
Refugio — Adrian, Horace F. (M).
Seminole — Capps, William M. (J) (C/S-S-J).

WYOMING

Laramie — Cordiner, Frank S. (J).

FRENCH MOROCCO

Sorel, Rene L. (J).

VENEZUELA

Cirigliano, Jose (M) (C/S-A-M). ★ ★ ★

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PETROLEUM BRANCH MEETING CALENDAR

JUNE Through NOVEMBER

JUNE

20	Kansas Section
21	South Plains Sub-Section
21	Oklahoma City Section
25	Pacific Petroleum Chapter

JULY

3	Delta Section
5	Illinois Basin Chapter
9	Mid-Continent Section
12	Pacific Junior Group
18	Kansas Section
19	South Plains Sub-Section
19	Oklahoma City Section
23	Pacific Petroleum Chapter

AUGUST

2	Illinois Basin Chapter
7	Delta Section
9	Pacific Junior Group
13	Mid-Continent Section
15	Kansas Section
16	South Plains Sub-Section
16	Oklahoma City Section
27	Pacific Petroleum Chapter

SEPTEMBER

4	Delta Section
6	Illinois Basin Chapter
10	Mid-Continent Section
11	East Texas Section
13	Pacific Junior Group
18	Gulf Coast Section
19	Southwest Texas Section
20	South Plains Sub-Section
20	Oklahoma City Section
24	Permian Basin Section
24	Pacific Petroleum Chapter

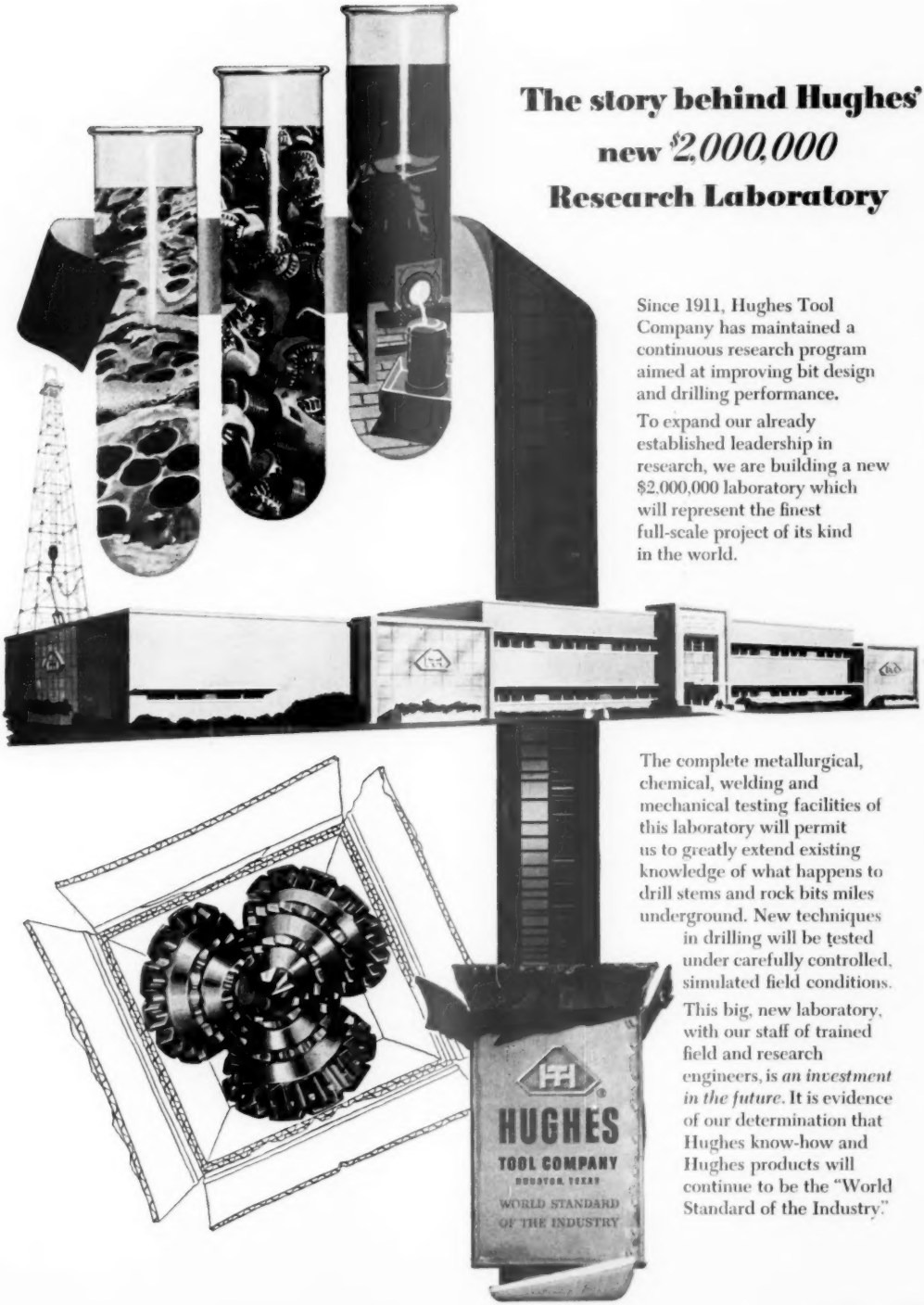
OCTOBER

2	Delta Section
3-5	Petroleum Branch Fall Meeting, Oklahoma City
4	Illinois Basin Chapter
8	Mid-Continent Section
9	East Texas Section
11	Pacific Junior Group
16	Gulf Coast Section
17	Southwest Texas Section
18	South Plains Sub-Section
18	Oklahoma City Section
22	Permian Basin Section
22	Pacific Petroleum Chapter
25-26	Petroleum Branch Fall Meeting, Los Angeles

NOVEMBER

1	Illinois Basin Chapter
6	Delta Section
8	Pacific Junior Group
12	Mid-Continent Section
13	East Texas Section
15	Oklahoma City Section
15	South Plains Sub-Section
20	Gulf Coast Section
21	Southwest Texas Section
21	Kansas Section
26	Pacific Petroleum Chapter
26	Permian Basin Section

The story behind Hughes' new $2,000,000 Research Laboratory

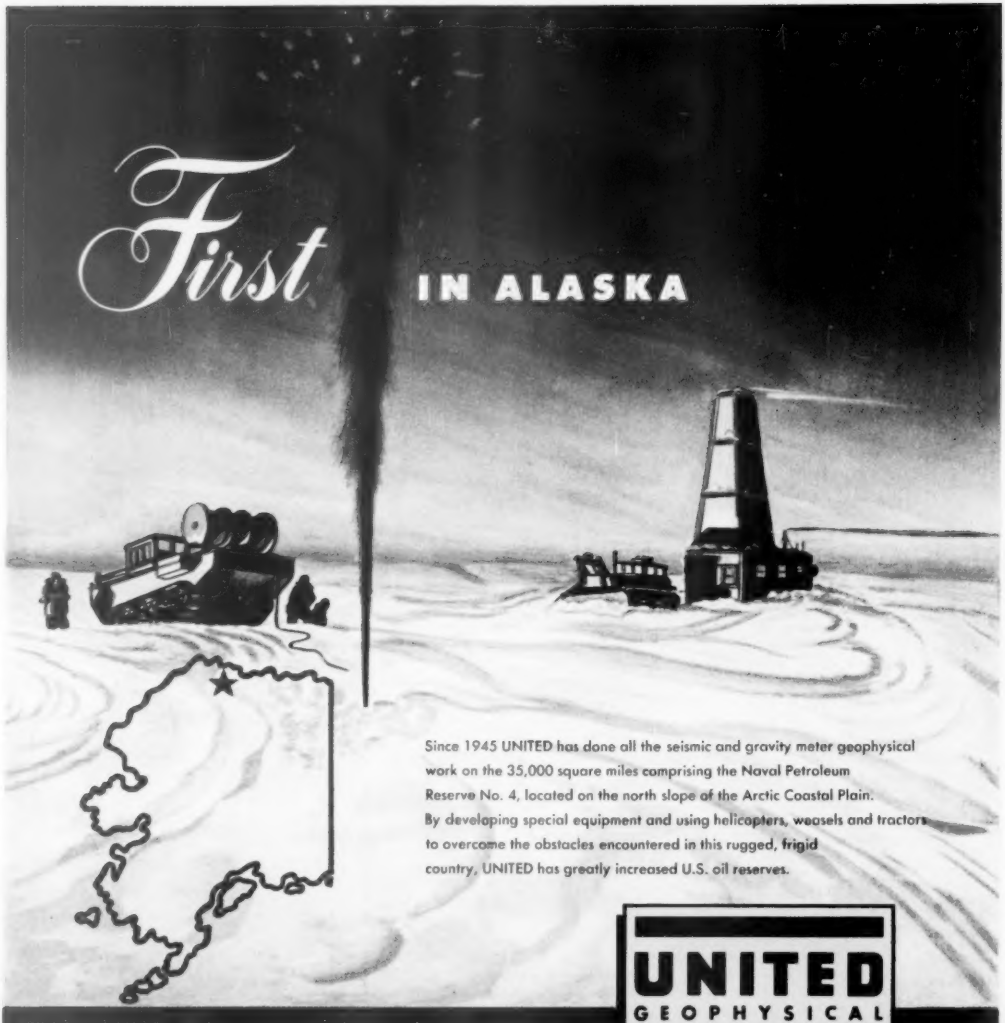


Since 1911, Hughes Tool Company has maintained a continuous research program aimed at improving bit design and drilling performance.

To expand our already established leadership in research, we are building a new $2,000,000 laboratory which will represent the finest full-scale project of its kind in the world.

The complete metallurgical, chemical, welding and mechanical testing facilities of this laboratory will permit us to greatly extend existing knowledge of what happens to drill stems and rock bits miles underground. New techniques in drilling will be tested under carefully controlled, simulated field conditions.

This big, new laboratory, with our staff of trained field and research engineers, is *an investment in the future.* It is evidence of our determination that Hughes know-how and Hughes products will continue to be the "World Standard of the Industry."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Since 1945 UNITED has done all the seismic and gravity meter geophysical work on the 35,000 square miles comprising the Naval Petroleum Reserve No. 4, located on the north slope of the Arctic Coastal Plain. By developing special equipment and using helicopters, weasels and tractors to overcome the obstacles encountered in this rugged, frigid country, UNITED has greatly increased U.S. oil reserves.
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JOURNAL OF PETROLEUM, June, 1951, Vol. 3, No. 6. In Two Sections-Section Two
TECHNOLOGY

American Institute of Mining and Metallurgical Engineers, Inc.

FOUNDED 1871

1951 DIRECTORY

of

OFFICERS, DIVISIONS, LOCAL SECTIONS,
STUDENT CHAPTERS AND COMMITTEES

CORRECTED TO MAY 1, 1951

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Basic Industries Research Lab.,
Allis-Chalmers Manufacturing Co.,
Box 512, Milwaukee 1, Wis.

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Established November 17, 1948

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Schlumberger Well Survey Corp.
Box 1034, Wichita, Kansas

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J.R. Berg, *Director* — E.L. Anders, *Director*

LEHIGH VALLEY

Established March 27, 1924

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H. R. Gault, *Vice Chairman*
J. S. Marsh, *Vice Chairman*
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Bethlehem, Pennsylvania

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E. A. Anderson, *Student Affairs*
M. L. Fuller, *Nominations*

MID-CONTINENT

Established December 28, 1917

Holds weekly luncheon meetings each Thursday in Tulsa, Oklahoma. Regular Section Meetings held second Monday each month except June through August.

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G. C. MacDonald, *Second Vice-Chairman (Membership)*
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Thompson Bldg., Tulsa, Oklahoma
Roy H. Smith, *Section Delegate*

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(Tulsa)

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A. E. Smith

Past Chairmen, ex officiis

H. M. Cooley Roy H. Smith

(Outside Tulsa)

Harold S. Kelly E. S. Messer

MINNESOTA

Established December 20, 1920

Annual meeting second week in January other meetings as called by officers

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W. N. Matheson, *Vice-Chairman*
E. P. Pfleider, *Vice-Chairman*
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1701 Foshay Tower
Minneapolis 2, Minnesota
Eugene P. Pfleider, *Section Delegate*

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Established October 17, 1913

Holds meetings the fourth Tuesday of each month

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C. H. Steele, *Vice-Chairman*
F. W. Strandberg, *Secretary-Treasurer*
Anaconda Copper Mining Company
421 Hennessy Bldg., Butte, Montana
F. W. Strandberg, *Section Delegate*

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R. H. Miller M. C. Mesmer

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Clarence Champ, *Student Awards*
A. B. Martin, *Nominating*

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M. H. Gidel, *Geology*
R. B. Caples, *Metallurgy*
A. E. Adami, *General*

NEVADA

Established January 21, 1916

Albin C. Johnson, *Chairman*
Albert Silver, *Vice-Chairman*
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U. S. Bureau of Mines
Box D, University Station
Reno, Nevada
J. C. Kinnear, Jr., *Section Delegate*

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RENO BRANCH

Luncheon meeting the first Thursday of each month

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Parker Lidell, *Secretary-Treasurer*
1500 Watt St., Reno, Nevada

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Established May 19, 1911

Holds monthly meetings except February, June, July, and August

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Established March 28, 1913

Holds meetings third Thursday of each month except June, July and August

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Established May 16, 1945

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Established November 19, 1920

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Established February 18, 1947

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Established April 22, 1921

Holds meetings third Friday of each month except during summer months

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Established February 17, 1914

Holds meetings alternately at Pottsville, Hazleton, Wilkes-Barre and Scranton. Spring meeting, April; Summer meeting, July; Fall meeting, October.

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Brownfield, Texas

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Re-established March 15, 1944

Dinner and meeting held last Thursday each month except June through September

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F. Foley, *Ex officio*

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Established 1920

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Aluminum Co. of America
New Kensington, Pennsylvania

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Ex Officiis
H. N. Eavenson — L. E. Young

S. Feigenbaum, *Chairman*
Annual All-Day Off-the-Record
Technical Session

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Established May 23, 1913

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511 Locust Street
St. Louis, Missouri

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Howard E. Butters, *Program Chairman*

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Established June 26, 1913

Holds meetings second Wednesday of each month except June through August; and Monday noons for luncheon at Engineers' Club

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Walter L. Penick, *Vice-Chairman*
J. G. Huseby, *Secretary-Treasurer*
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San Francisco 4, California

E. H. Wisser, *Section Delegate*

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Established May 23, 1913

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Ian Campbell, *Past Chairman Mining Branch*

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Established February 1951

SOUTHWEST TEXAS

Established September 18, 1946

Holds meetings second Wednesday of each month except July, August and December

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George Wilson, *Vice-Chairman*
Harry D. Vaughan, *Secretary-Treasurer*
Lane Wells Co., P. O. Box 389
Corpus Christi, Texas

Lee J. Thronson, *Section Delegate*

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Established September 30, 1947

Holds meetings second Wednesday in January, April, July and October

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Established May 27, 1926

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Established October 25, 1918

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UTAH

Established April 24, 1914

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Established May 16, 1930

Holds regular meetings quarterly; special meetings when speakers are available.

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Union Pacific Railroad Company
Box 1072, Rock Springs, Wyoming

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WASHINGTON, D. C.

Established June 21, 1918

Holds meetings usually third Tuesday of each month except June through August

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FOREIGN SECTIONS

MEXICO

Established 1950

Holds monthly luncheon meetings first Monday of each month at American Club, Mexico City

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Established January 20, 1939

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Established April 17, 1936

Holds meetings Thursday of each month at Av. Rio Branco 128, Room 410

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Harvey Hakala, *Vice-Chairman*
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